TECHNICAL REPORT ECOM-00394-14

HIGH VOLTAGE BREAKDOWN STUDY

FOURTEENTH QUARTERLY PROGRESS REPORT

16 February 1968 through 15 May 1968

Prepared by:

ION PHYSICS CORPORATION

BURLINGTON, MASSACHUSETTS

OCTOBER 1968

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Technical Report ECOM-00394-14

HIGH VOLTAGE BREAKDOWN STUDY

Fourteenth Quarterly Progress Report
16 February 1968 through 15 May 1968

Report No. 14

Contract No. DA-28-043-AMC-00394(E)
AMC Task No. 7900.21.243.40.00

Prepared for

U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY 07703

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order No. 517

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ION PHYSICS CORPORATION
BURLINGTON, MASSACHUSETTS

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PURPOSE

The factors influencing breakdown in high voltage vacuum devices will be studied. The information obtained will provide the basis for improvement in the design of microwave and modulator tubes that must operate at voltages greater than 100 kilovolts without breakdown.

ABSTRACT

The results of nine further treatments are reported from a 32-block, 5-factor, full-factorial experiment now underway to investigate the main effects and interactions of the following factors: anode and cathode material (copper and aluminum), electrode treatment (hydrogen or vacuum fired), anode size and shape (Bruce or sphere). By a process of stacking, the effect of a transverse magnetic field, exposure and energy storage will also be investigated.

LECTURES, CONFERENCES AND PUBLICATIONS

Lectures and Conferences

27 February 1968

M. Chrepta visited IPC to see tests in progress and discuss the proposed crowbar system to be used in conjunction with the energy storage (7 kJ).

17 April 1968

M. J. Mulcahy visited Fort Monmouth to discuss progress under the contract and analysis of the results.

7 May 1968

Visit to Raytheon Company, Waltham, Massachusetts, by W. R. Bell, A. Watson and C. Boudreau. This is the first of a series of proposed visits to manufacturers of high power tubes and its objectives were:

(1) to acquaint the manufacturers of progress under the contract;

(2) to get feedback from them on their current procedures and techniques in tube manufacture (viz, firing temperature, electrode material, treatment and fabrication, etc);

(3) to get feedback from them on problems, areas or lines of investigation which might be incorporated into the present program or the next phase of it.

Discussions took place along these lines.

SECTION 1

INTRODUCTION

The work reported herein describes the fourteenth three months of a study of high voltage breakdown in vacuum with particular application to problems encountered in the development of high power vacuum tubes.

The objective of this period was to continue tests of a 32-block experiment (5-factor, full factorial) involving aluminum and copper electrodes. By a technique of stacking, flexible factors (magnetic field, exposure and energy storage) are also investigated.

The results of nine further successful treatments are reported here in addition to the first four treatments which were given in the previous Quarterly Report.

A theory of vacuum breakdown, based on gas evolution at the anode is almost complete and will be included as a separate report, an addendum to the present Quarterly Progress Report.

SECTION 2
300 KV TEST VEHICLE

2.1 Vacuum Chamber and System

Examination of the records to date has shown that the main chamber has had 86 full bakes and nine trial bakes. Gold O-ring surfaces have been machined twice and the chamber inside wall electro-polished once and acid cleaned once. During the month of May, the lower flange was welded to the spherical chamber. This has removed a troublesome gold seal.

2.2 Feedthrough Bushing

The original bushing has been used for all but three treatments. The new bushing was sand blasted, cleaned and baked for 72 hours in a separate vacuum chamber. It still did not condition as quickly as the original and on the third test it was limited at 220 kV. Glow cleaning in hydrogen for 30 minutes gave some improvement and this approach is being pursued. Meanwhile, the original bushing was reinstalled in the chamber and is operating satisfactorily.

2.3 High Voltage Power Supply

Sparking developed in the pressure vessel below the vacuum chamber, but this was solved by adding a stress relieving shield.

2.4 Baking System

The new mantle has successfully completed 29 bakes to date without serious problems. After cathode heater failure on treatment 13, a redesigned cathode mount was installed (Figure 1). This incorporates the IPC-Hotwatt heater and eliminates the remaining feedthrough heater wires and heater welds from the vacuum envelope.

2.5 Energy Storage System

Minor modifications to the grounding system of the energy storage are being introduced. The high pressure crowbar switch is being checked out to determine the overall time lag from initiation to full closure. This delay will be 1 μsec or less.

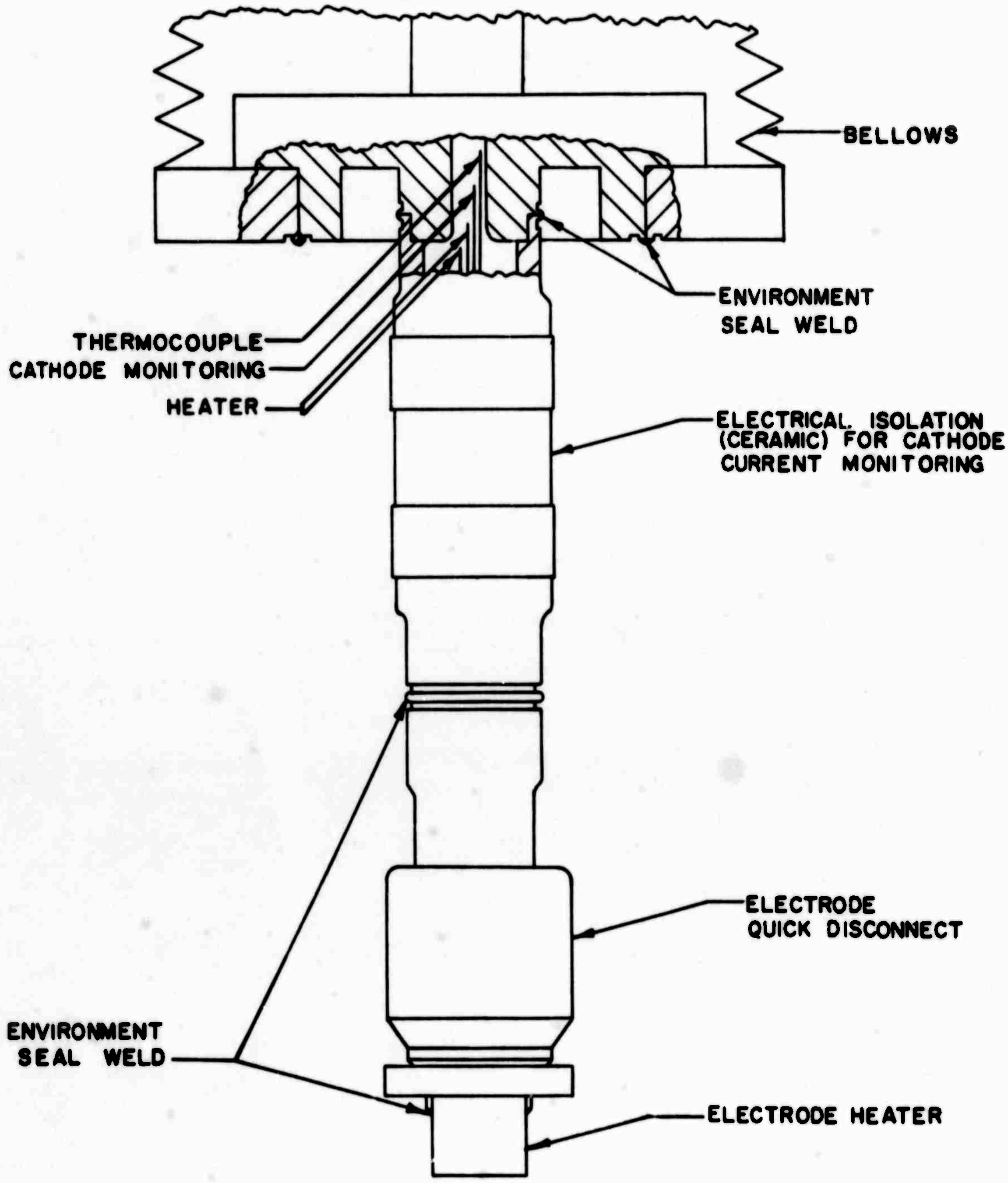

Figure 1. New Cathode Mount

1-2773

2.6 Dielectric Envelope

This is being manufactured (see Figure 1, Thirteenth Quarterly Report), and will be installed for trial tests at the end of an experiment.

This has been sent out for metalizing the ends, and the support structure and end planes are currently being manufactured. The complete unit (Figure 2) is scheduled for installation and test in the chamber prior to the start of the second 16 treatments of the 32-block experiment. Subsequently, it will be installed at the end of the third day of each treatment after completion of the energy storage section.

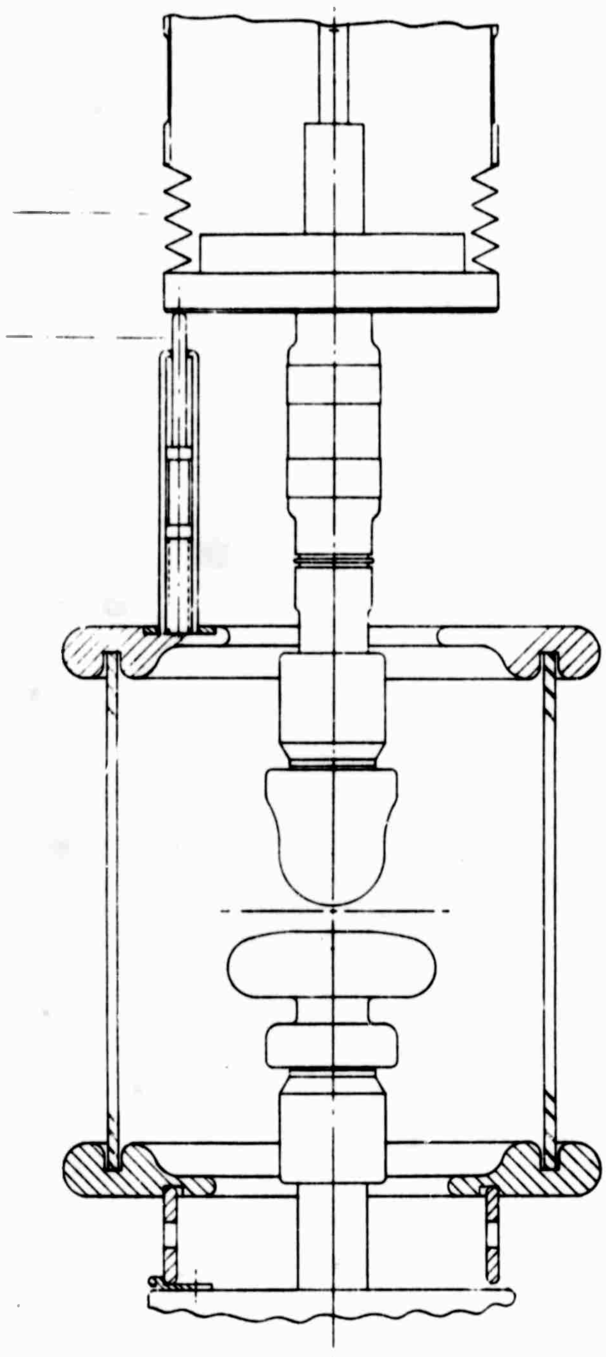

Figure 2. Dielectric Envelope Assembly

1-2545

SECTION 3

RESULTS OF TREATMENTS 5 THROUGH 13

3.1 Experimental Results

The results for the first four treatments (abe, abde, abcde and e) were given in the previous Quarterly Report. The results of treatments abce, de, ace, be, ce, ade, ae, ade, acde, are reported here in Tables 1, 2 and 3 and are plotted in Figures 3 through 29. Insufficient data is available as yet to carry out a meaningful statistical analysis. Likewise, although the results show interesting trends, physical analysis and discussion of these also seems premature at this stage and will, therefore, be held over until completion of the 16-treatment block. Three treatments will be replicated.

3.2 Theory of Vacuum Breakdown

A report is being prepared to include theoretical ideas developed during the program to date. The theory appears to be successful in accounting for many experimental data, particularly the magnetic effects. The report will be included as an addendum to this Quarterly Progress Report.

Table 1. Results for Day 1

Treatment	Gap (cm)								
	1.0	1.0	1.0	1.5	2.0	3.0	0.25	0.50	0.75
abce	80	110	120	200	266	300 No BD	33	80	123
de	100	100	120	170	210	290	30	89	120
ace	127	150	190	268	277	290	57	127	160
be	220	220	210	262	262	260	45	90	140
ce	130	150	170	260	282	300 No BD	66	117	170
cde	100	133	150	220	270	296	28	105	165
ae	145	167	180	240	280	295	47	105	152
ade	130	150	170	240	252	300 No BD	31	86	139
acde	170	170	190	250	290	300 No BD	40	109	157

Treatment	Gap (cm)							
	1.0	1.5	2.0	3.0	0.25	0.5	0.75	1.0
abce	150	190	250	300	37	100	146	160
de	160	220	280	300	56	90	135	180
ace	200	267	280	293	67	120	190	230
be	180	230	260	290	47	103	150	175
ce	200	270	294	300	62	115	185	230
cde	200	260	290	297	37	118	150	200
ae	220	269	290	300 No BD	49	124	179	220
ade	150	220	240	300 No BD	44	96	142	190
acde	190	230	260	300	58	112	166	210

Table 2. Results for Day 2

Treatment	Gap (cm)																			
	1.0					2.0					0.25					0.5				
	Field (Gauss)																			
	0	100	200	300	400	0	100	200	300	400	0	100	200	300	400	0	100	200	300	400
abce	166	170	180	200	180	280	240	270	279	279	57	70	77	85	83	170	159	170	150	160
	170					290					94					149				
de	188	187	200	140	169	250	220	210	270	260	38	42	45	44	48	90	100	90	96	97
	140					280					42					95				
ace	206	200	200	200	200	282	278	280	260	270	55	57	57	65	63	135	147	144	150	154
	200					260					66					150				
be	199	150	160	160	170	275	250	220	210	230	44	40	50	50	50	100	109	104	100	105
	170					278					51					90				
ce	217	220	200	190	180	296	260	280	260	230	53	60	67	70	75	140	130	136	130	130
	230					291					74					135				
cde	219	190	190	200	200	280	230	250	220	230	58	55	58	61	54	109	126	103	110	127
	190					210					58					127				
ae	216	110	150	150	170	250	251	260	260	250	50	52	60	61	60	149	140	150	150	158
	170					279					69					140				
ade	170	160	180	190	150	259	257	220	210	210	35	39	42	40	44	109	110	116	110	100
	176					260					46					119				
acde	190	204	220	166	170	272	230	240	230	240	60	69	67	79	77	147	150	157	150	140
	209			*	*	260					78					159			*	*

* Not Visible

Table 3. Results for Day 3

Treatment	Gap (cm)														
	1.0			1.5			2.0			0.25			0.5		
	Field (Gauss)														
	0	200	400	0	200	400	0	200	400	0	200	400	0	200	400
abce	268	260	240	290	283	289	300	290	291	110	100	102	190	170	400
	230			297						130			200		
de	186	190	190	264	237	250	300	260	270	45	60	60	104	117	117
	200			250			*			58			119		
ace	220	210	200	270	256	260	280	230	290	76	99	96	170	170	160
	240			270			290			100			170		
be	188	159	140	227	180	180	300	210	200	48	48	50	94	100	105
	190			220			300			55			106		
ce	240	237	217	250	260	260	231	280	285	75	88	88	130	150	150
	240			270			230			87			148		
cde	200	209	190	240	220	220	280	255	240	49	40	50	106	120	125
	210			250			285			50			120		
ae	225	227	220	249	260	260	257	290	290	62	70	80	160	177	170
	234			270			266			95			170		
ade	239	210	200	250	220	240	290	250	235	49	63	66	140	140	150
	220			280			277			70			120		
acde	210	190	180	240	240	220	270	260	230	90	100	104	180	179	188
	214		**	239		**	270		**	105			160		

* No breakdown
** Not visible

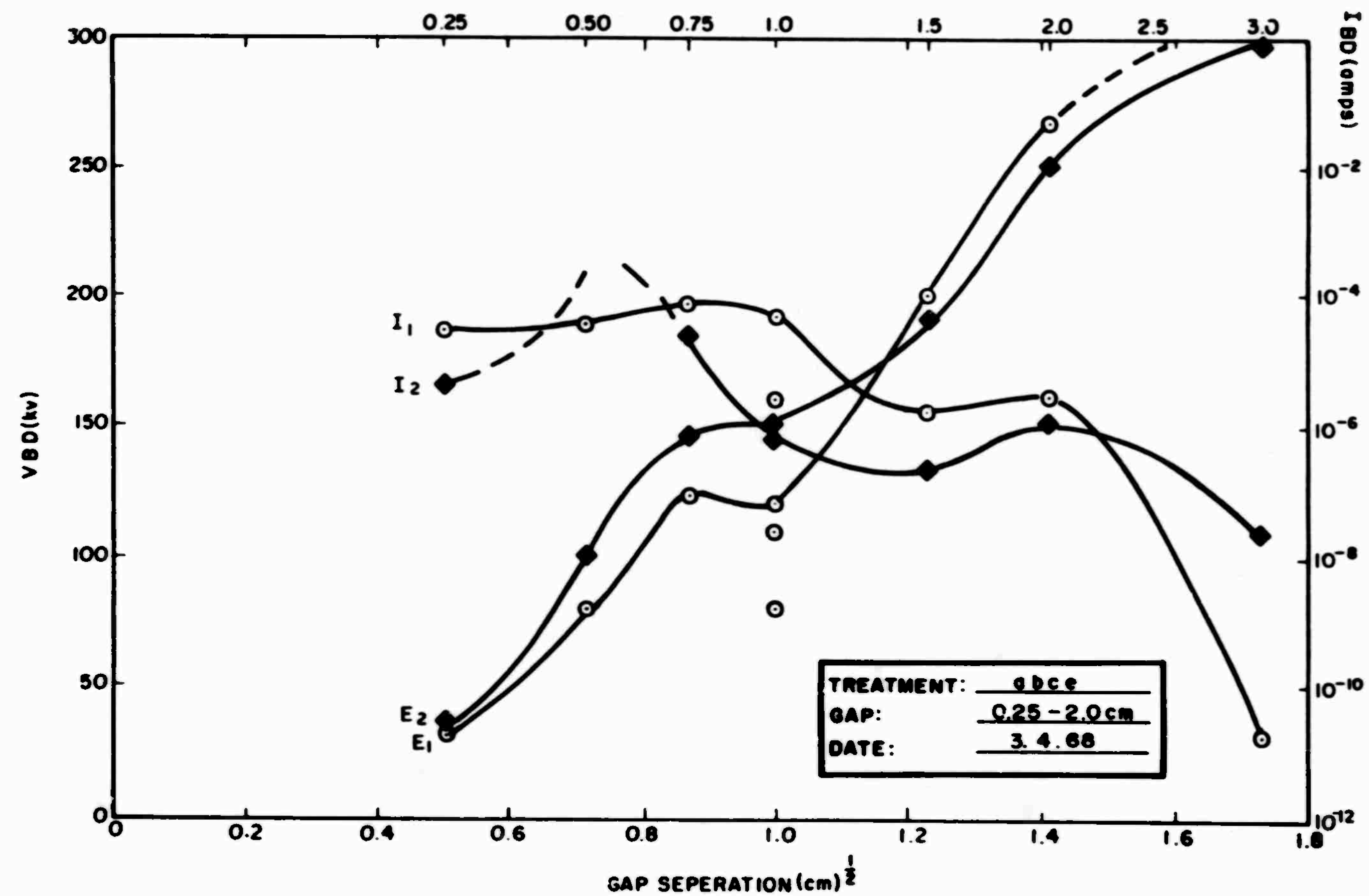

Figure 3. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment abce

1-2979

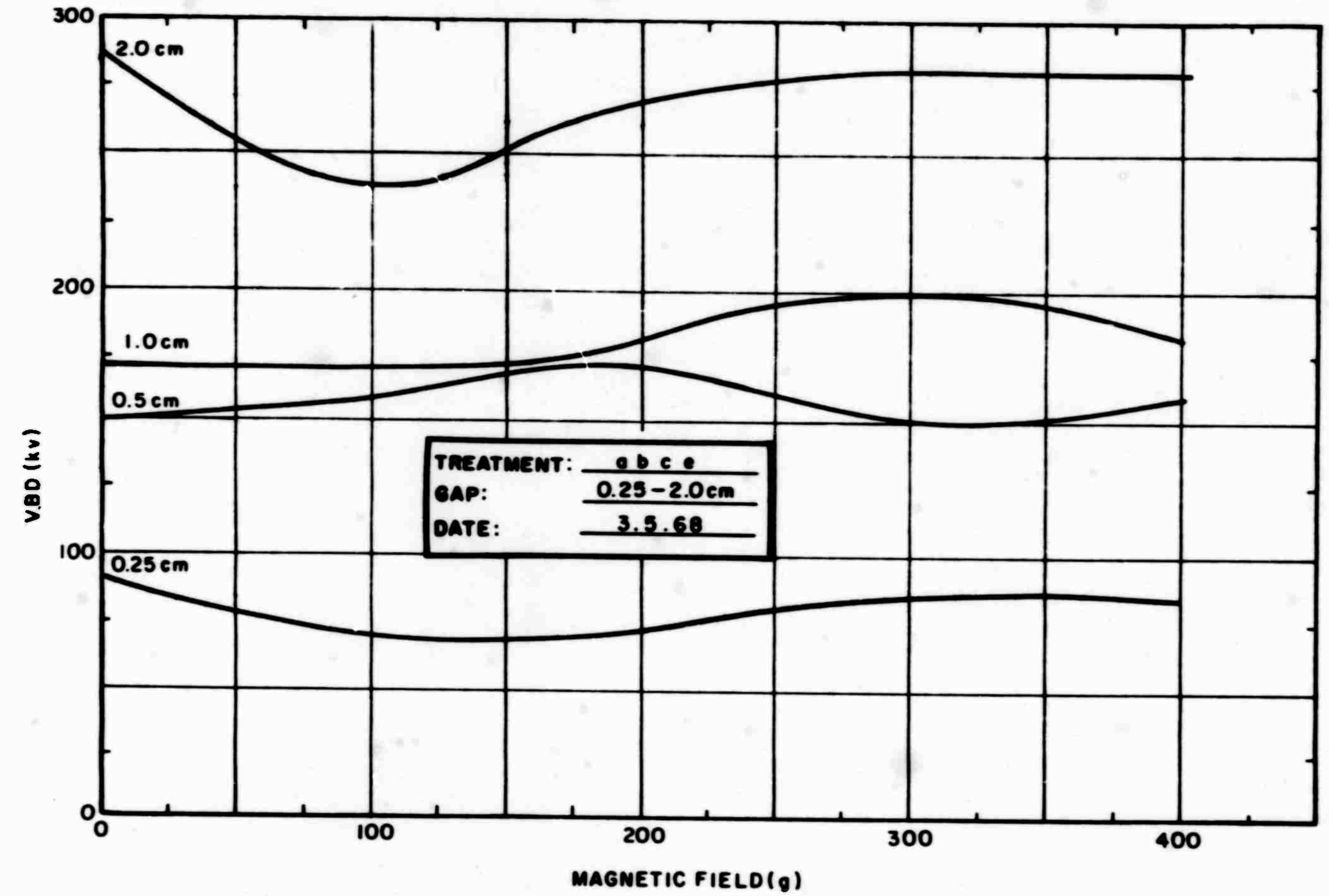

Figure 4. Variation of V_{BD} with Magnetic Field for Treatment abce

1-2980

1-2981

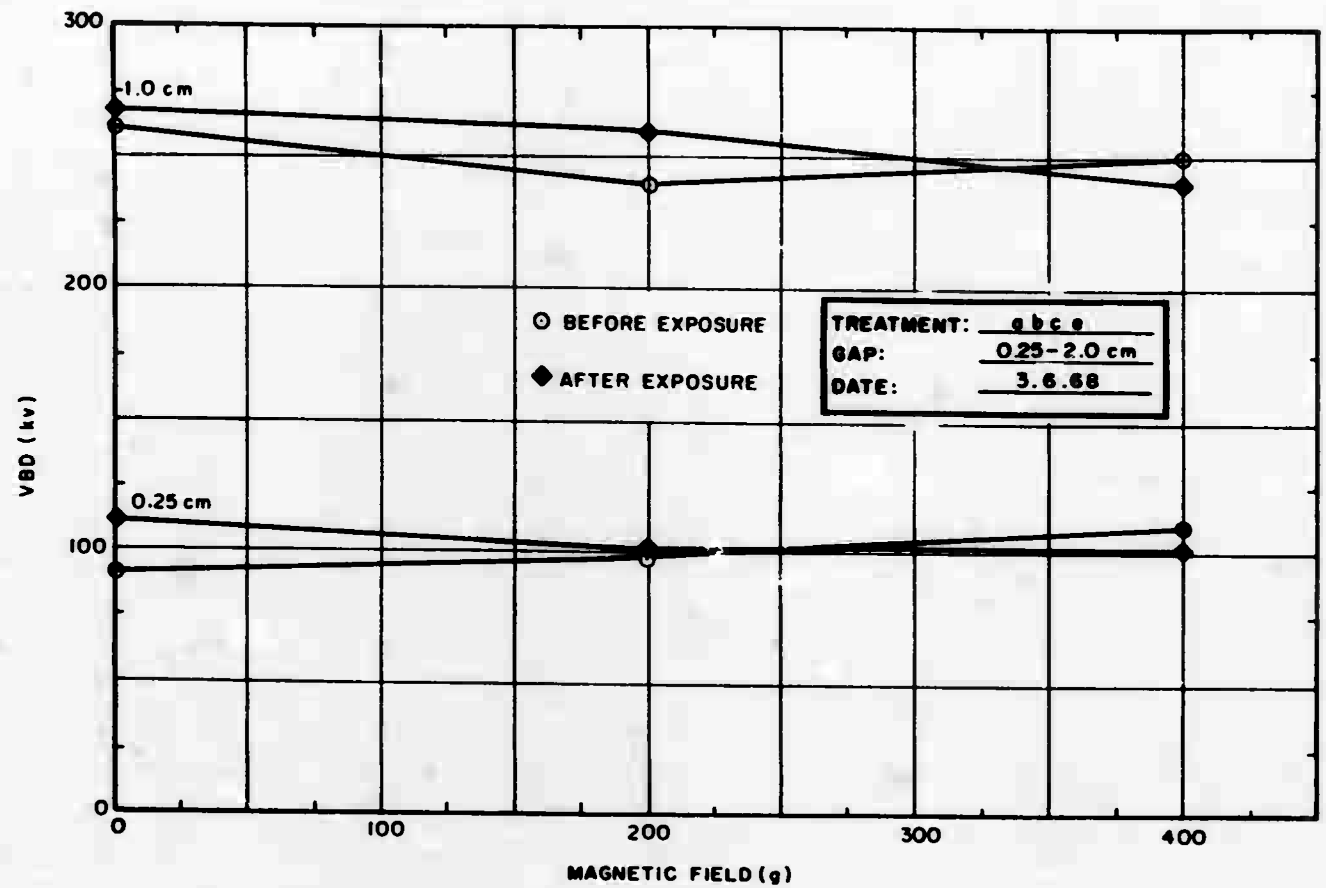

Figure 5. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment abce

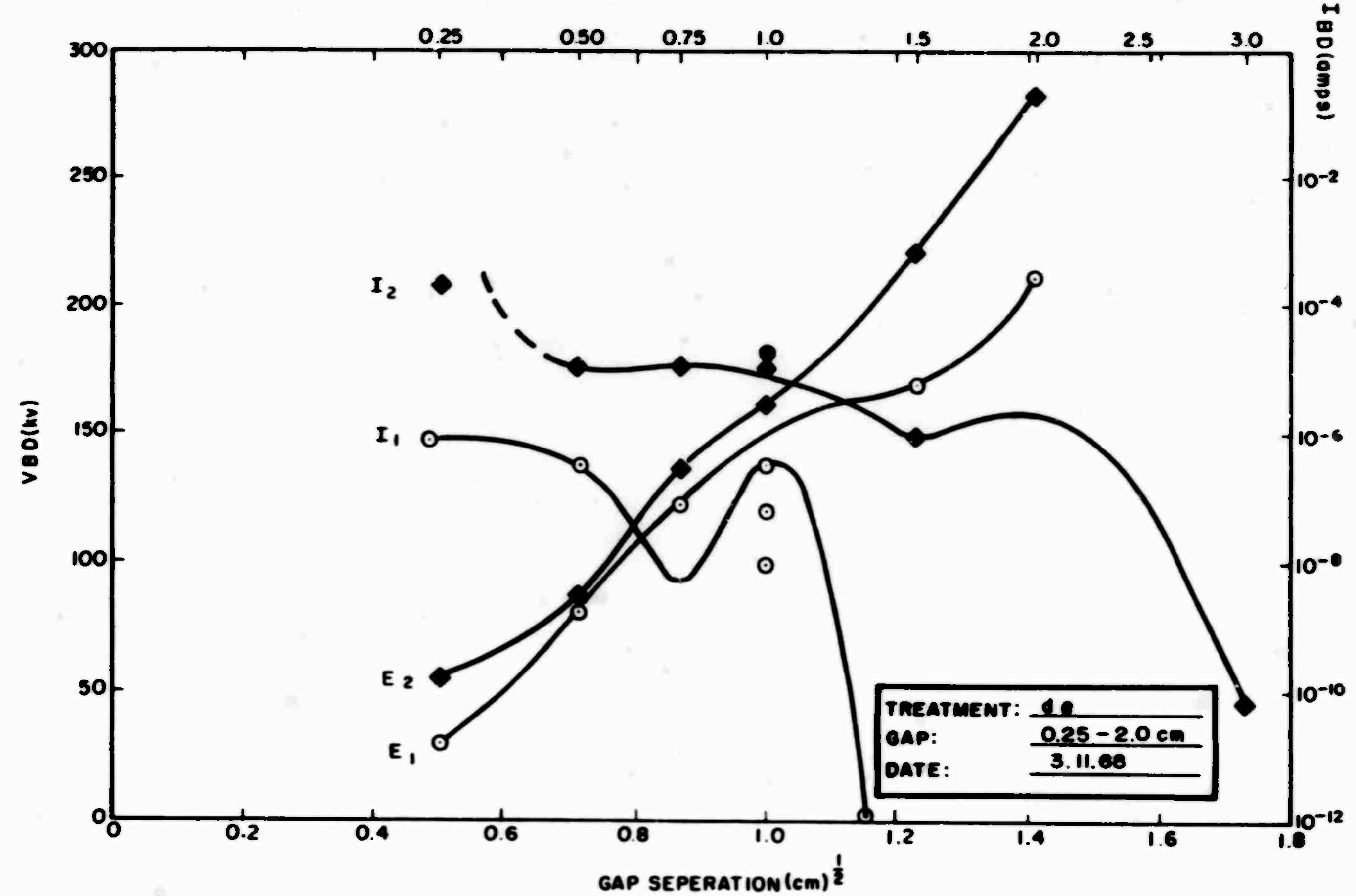

Figure 6. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment de

1-2982

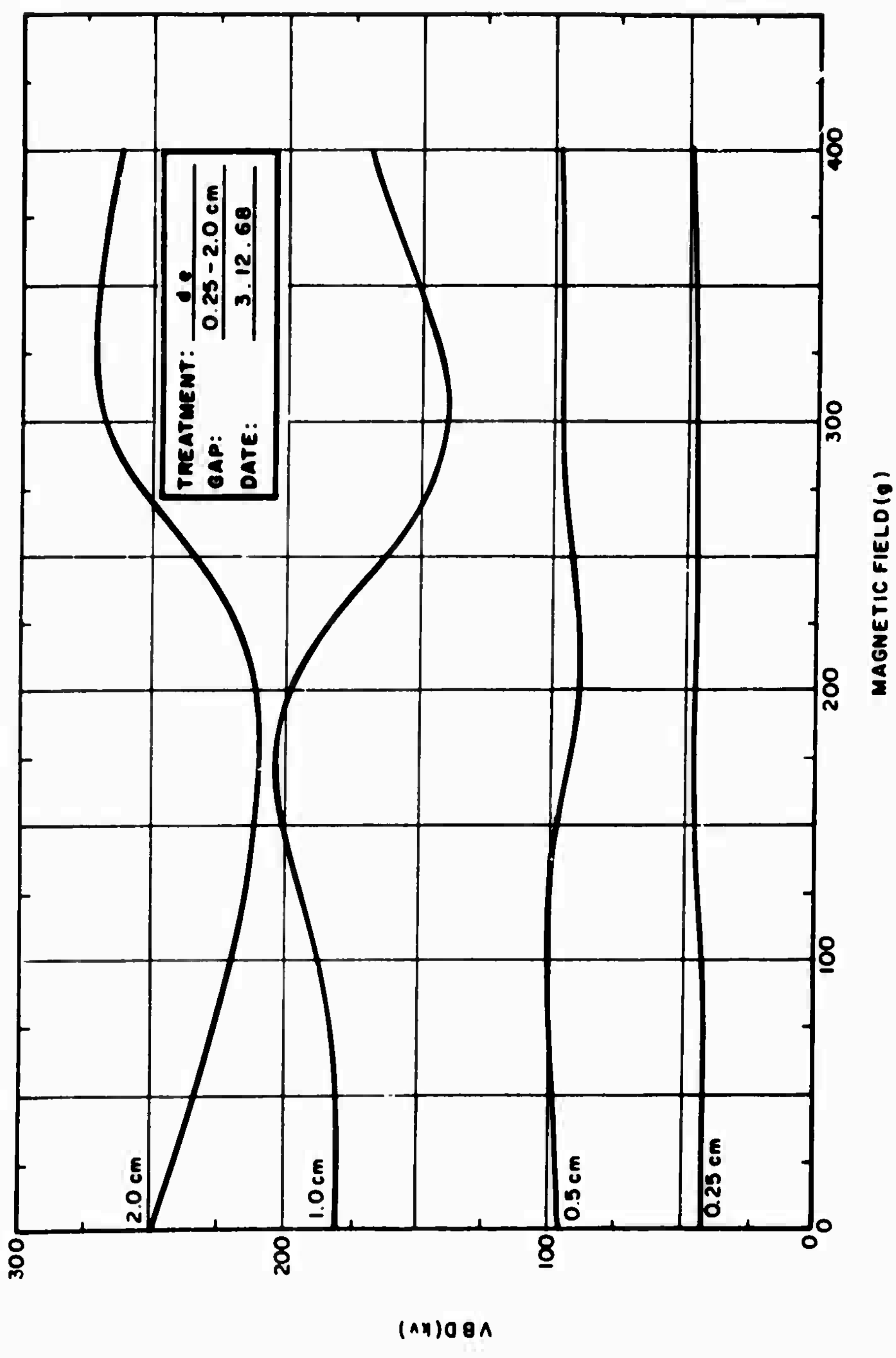

Figure 7. Variation of V_{BD} with Magnetic Field for Treatment de

1-2983

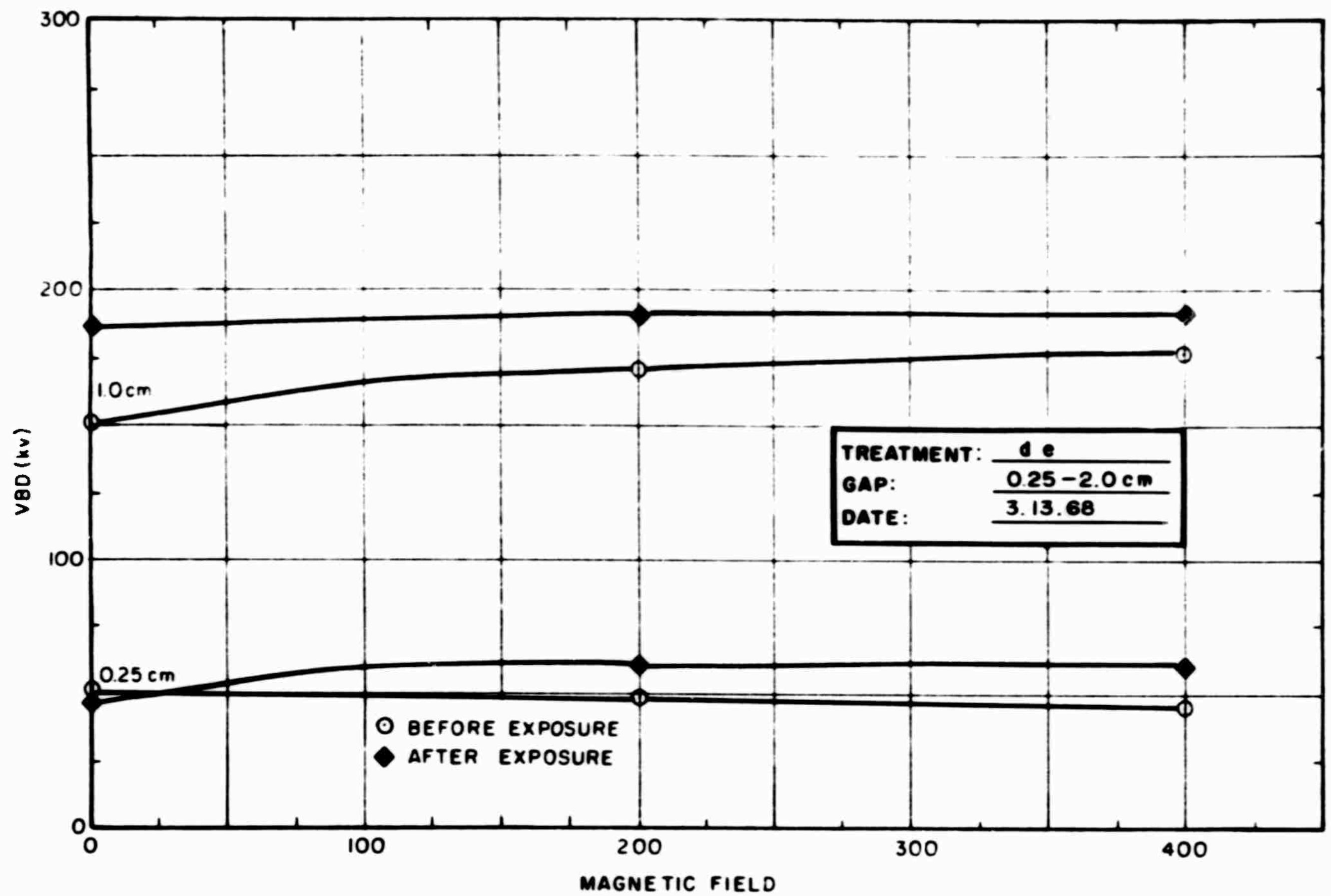

Figure 8. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment de

1-2984

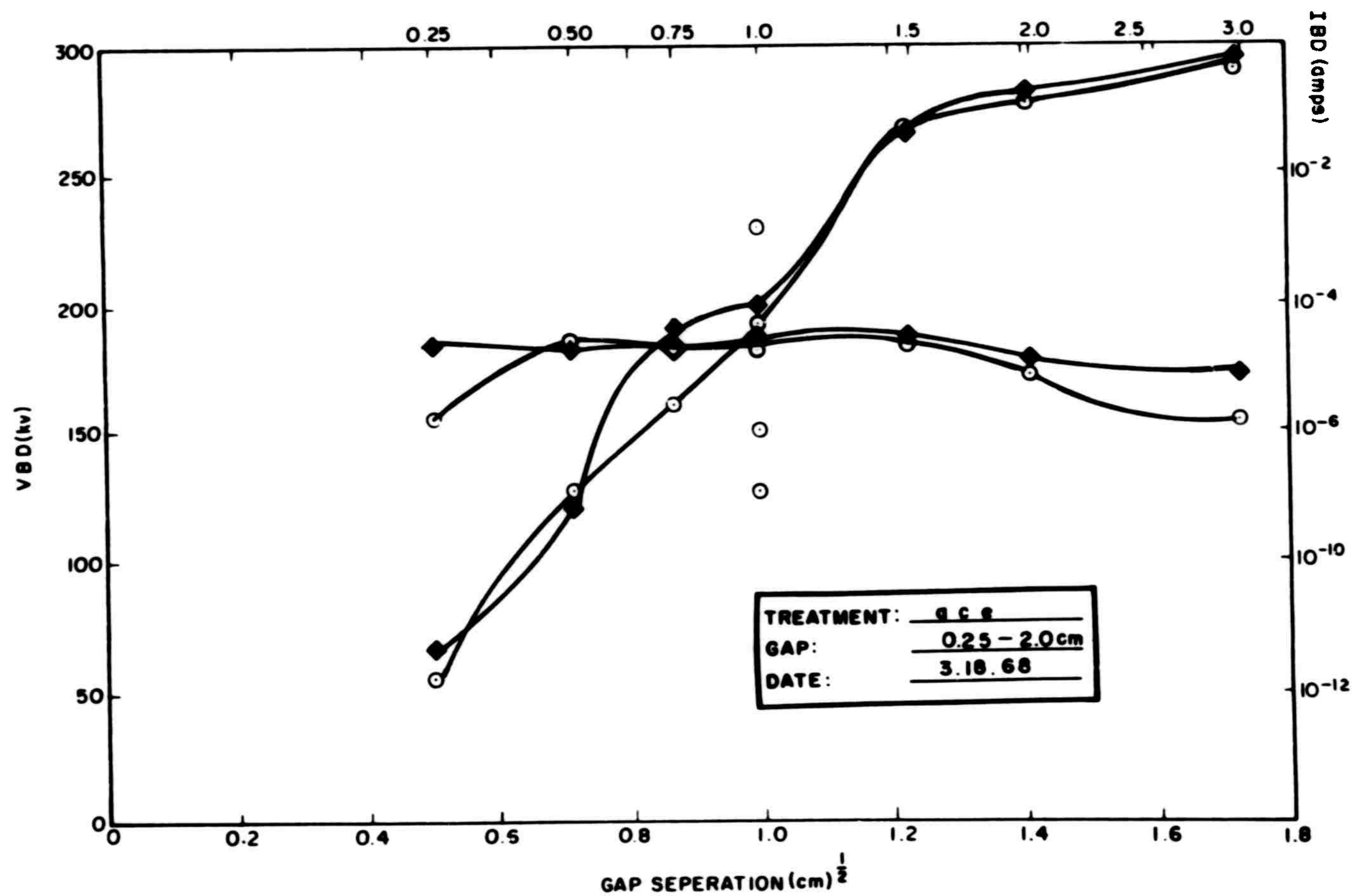

Figure 9. Variation of V_{BD} and Maximum Prebreakdown Current With Gap Separation for Treatment ace

1-2985

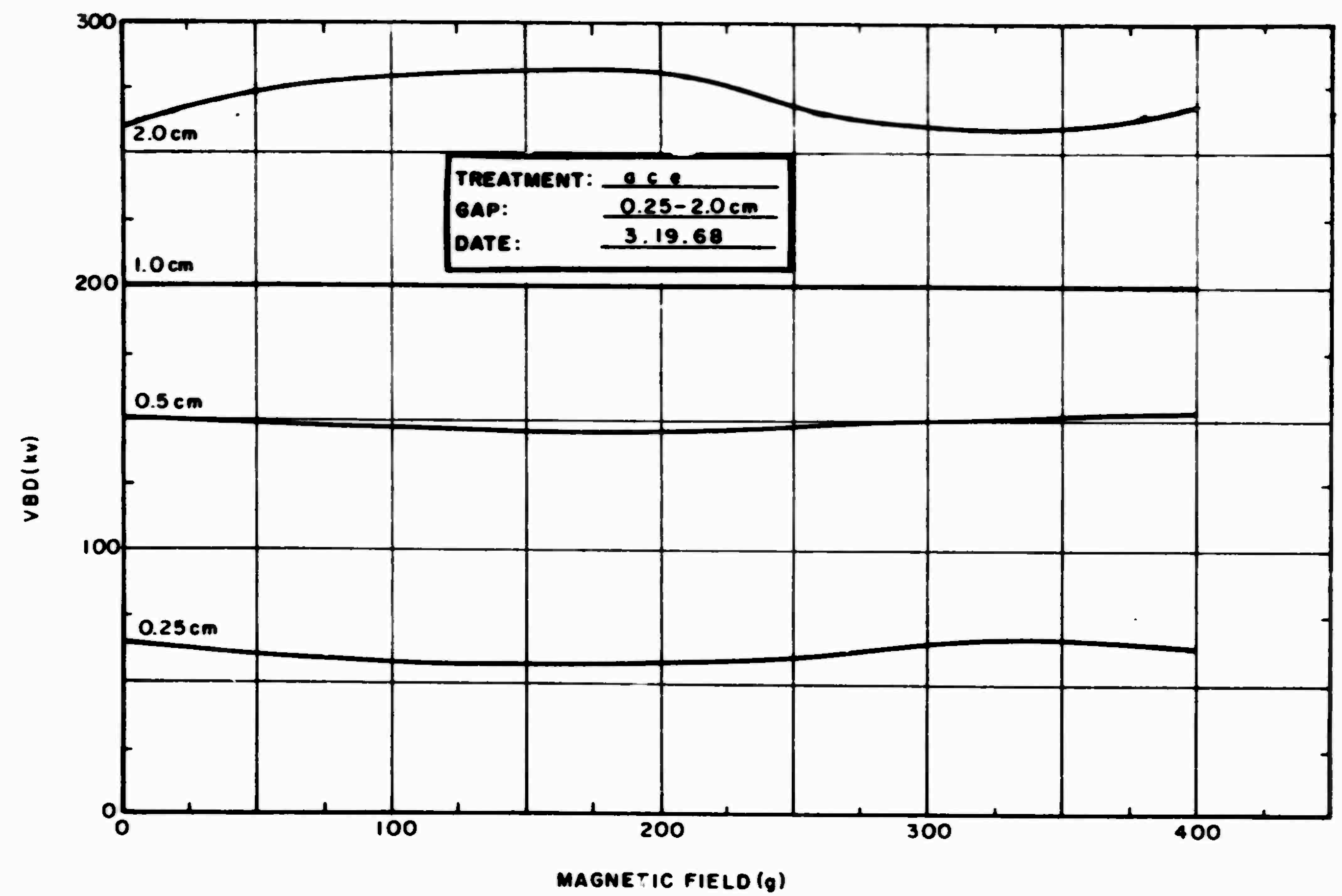

Figure 10. Variation of V_{BD} with Magnetic Field for Treatment ace

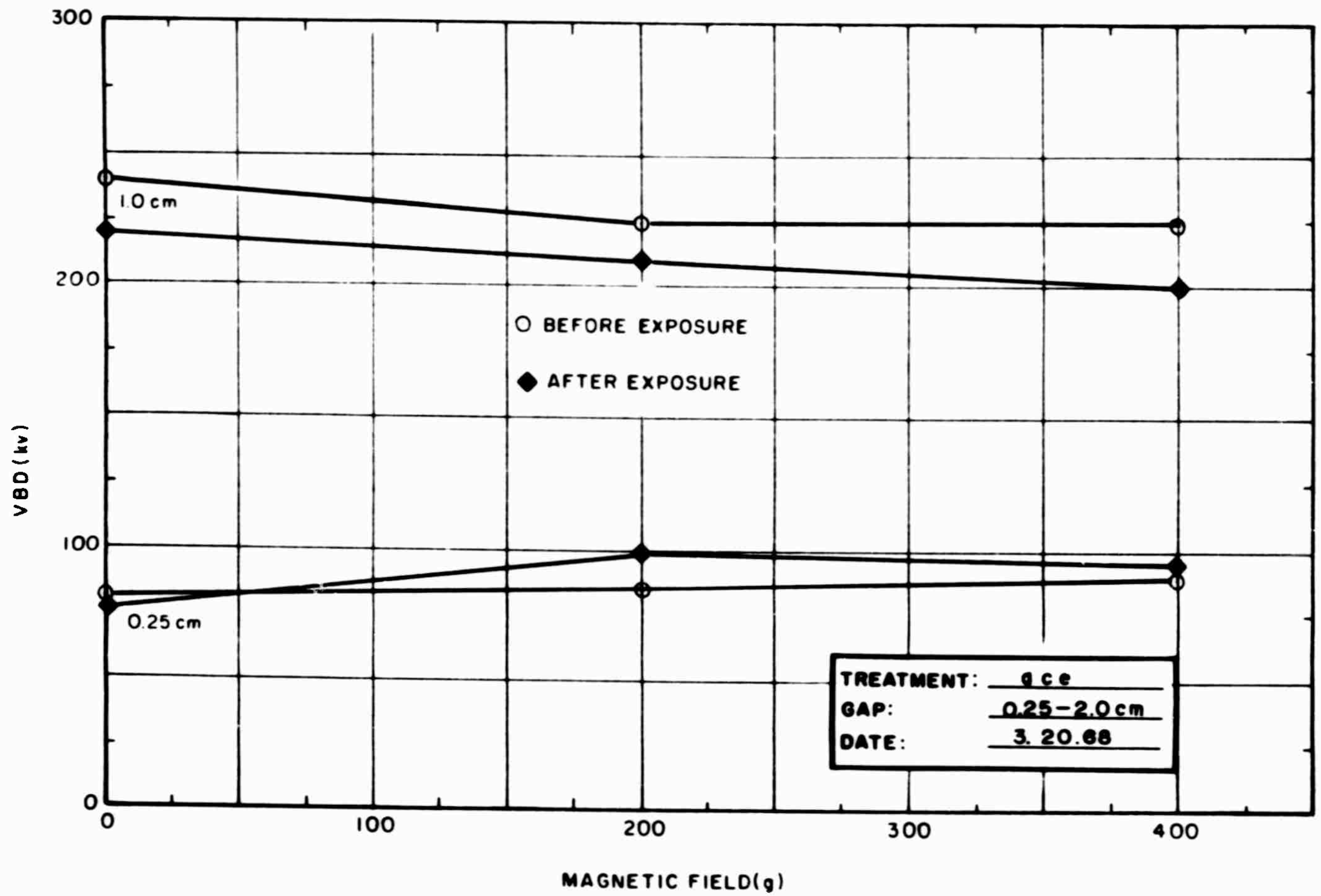

Figure 11. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment ace

1-2987

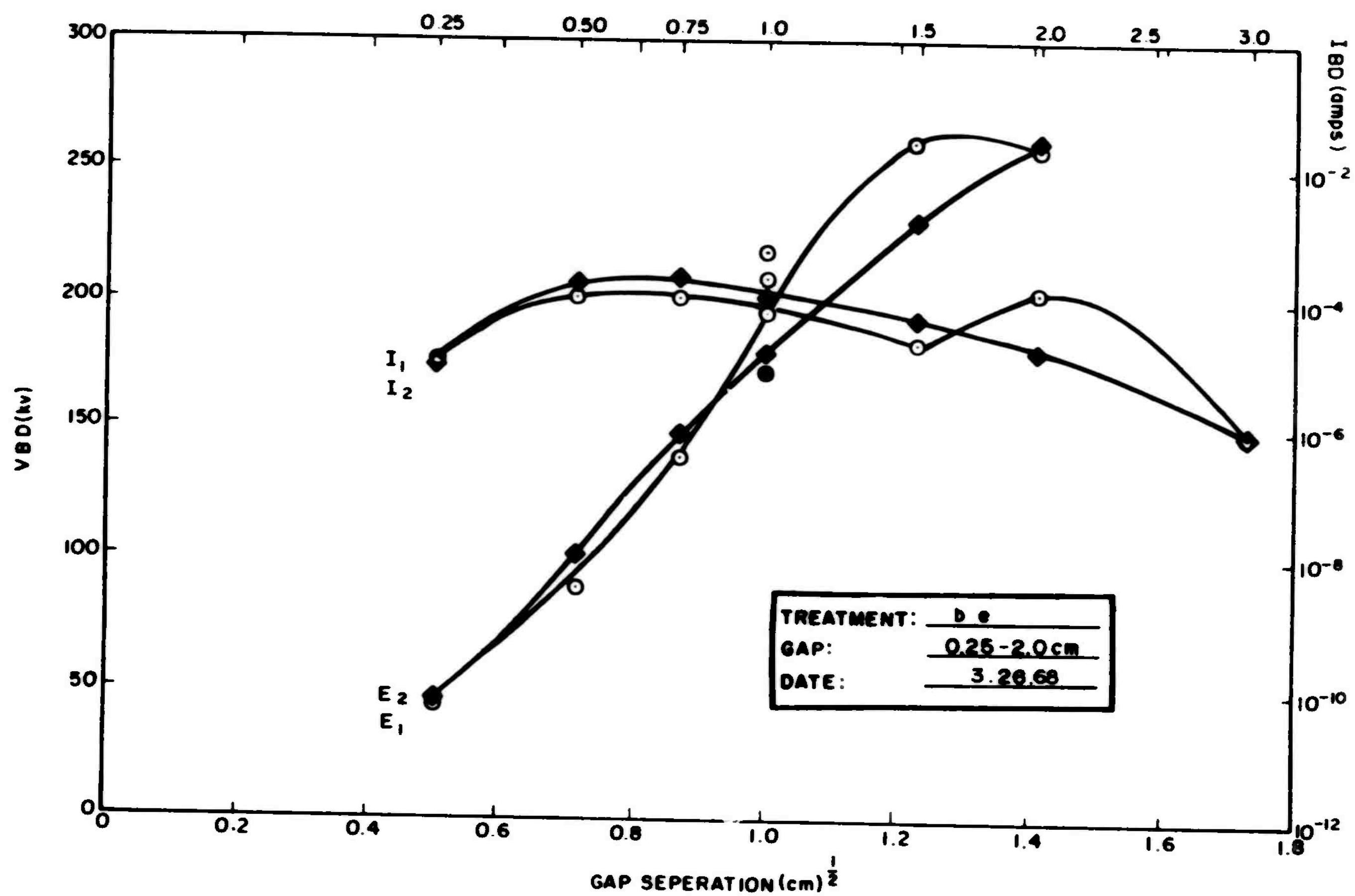

Figure 12. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment be

1-2988

1-2989

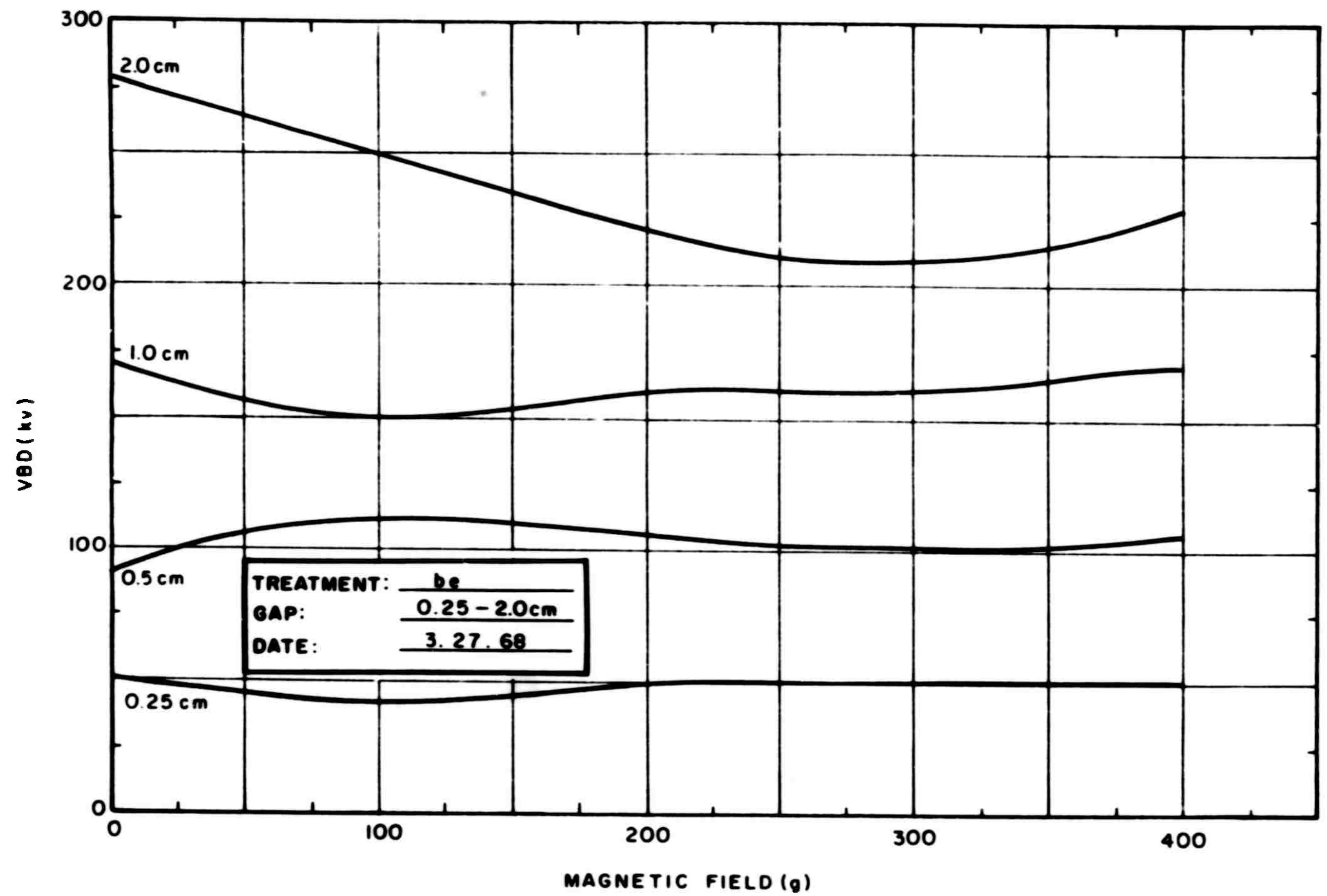

Figure 13. Variation of V_{BD} with Magnetic Field for Treatment be

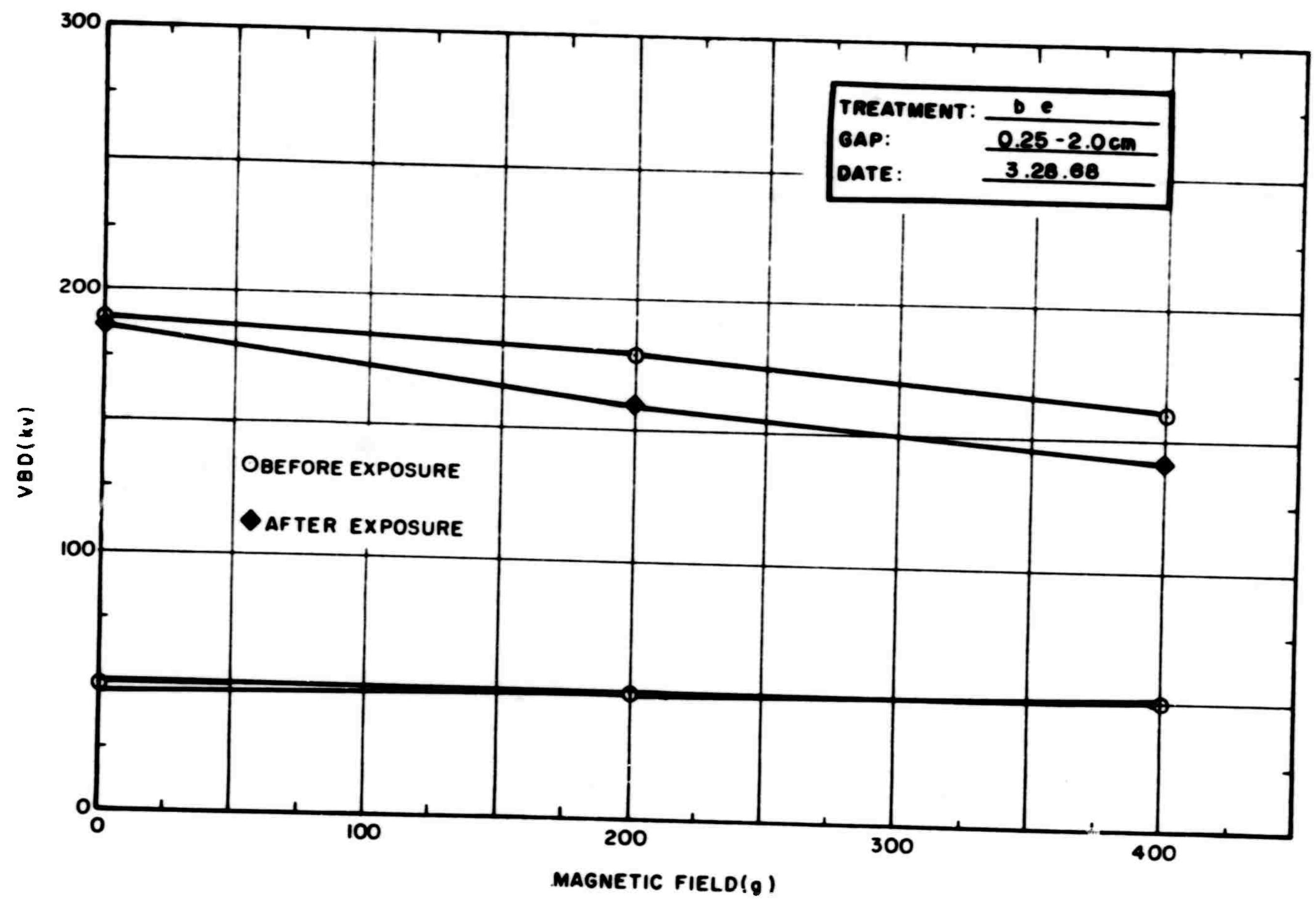

Figure 14. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment be

1-2990

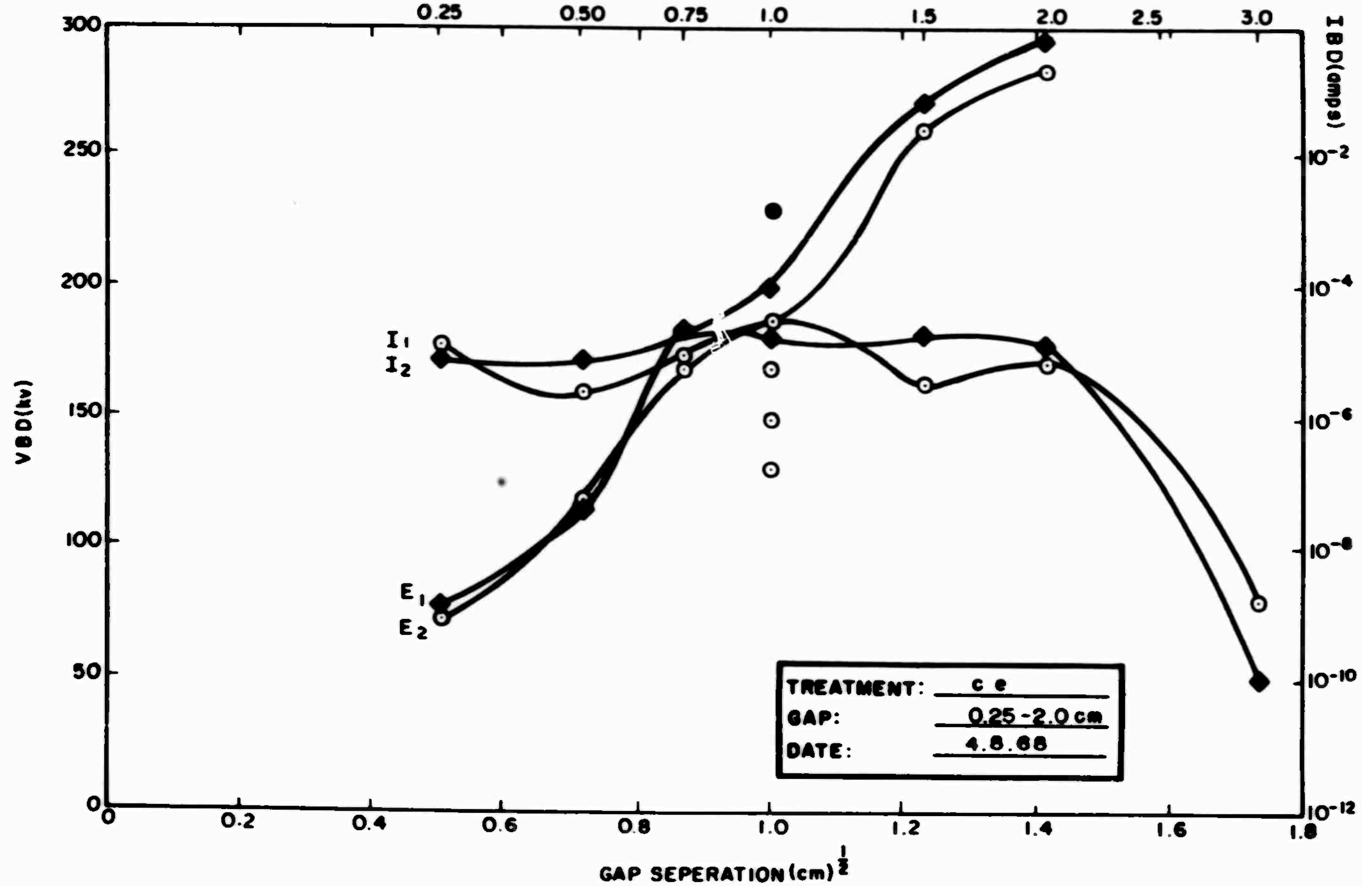

Figure 15. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment ce

1-2991

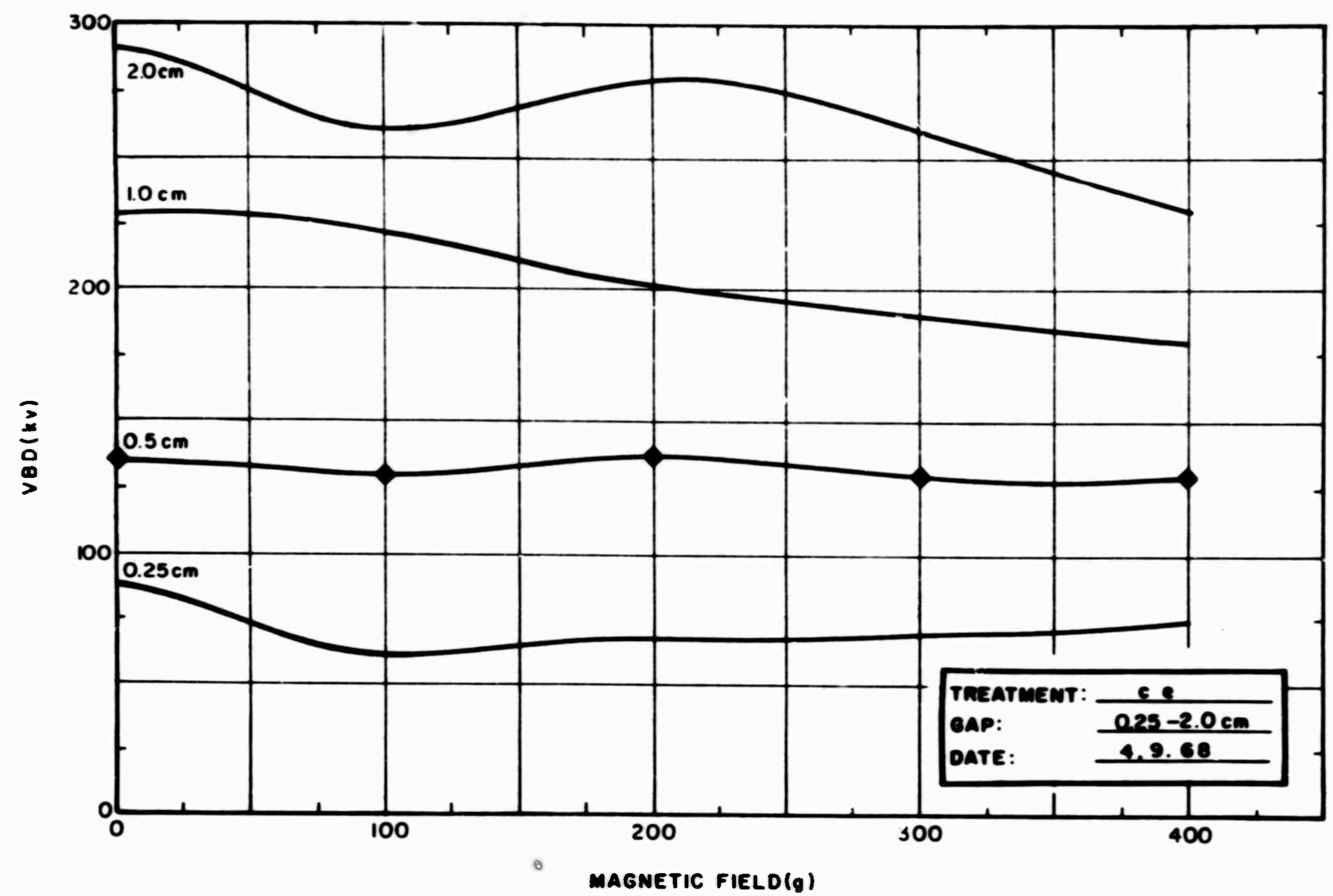

Figure 16. Variation of V_{BD} with Magnetic Field for Treatment ce

1-2992

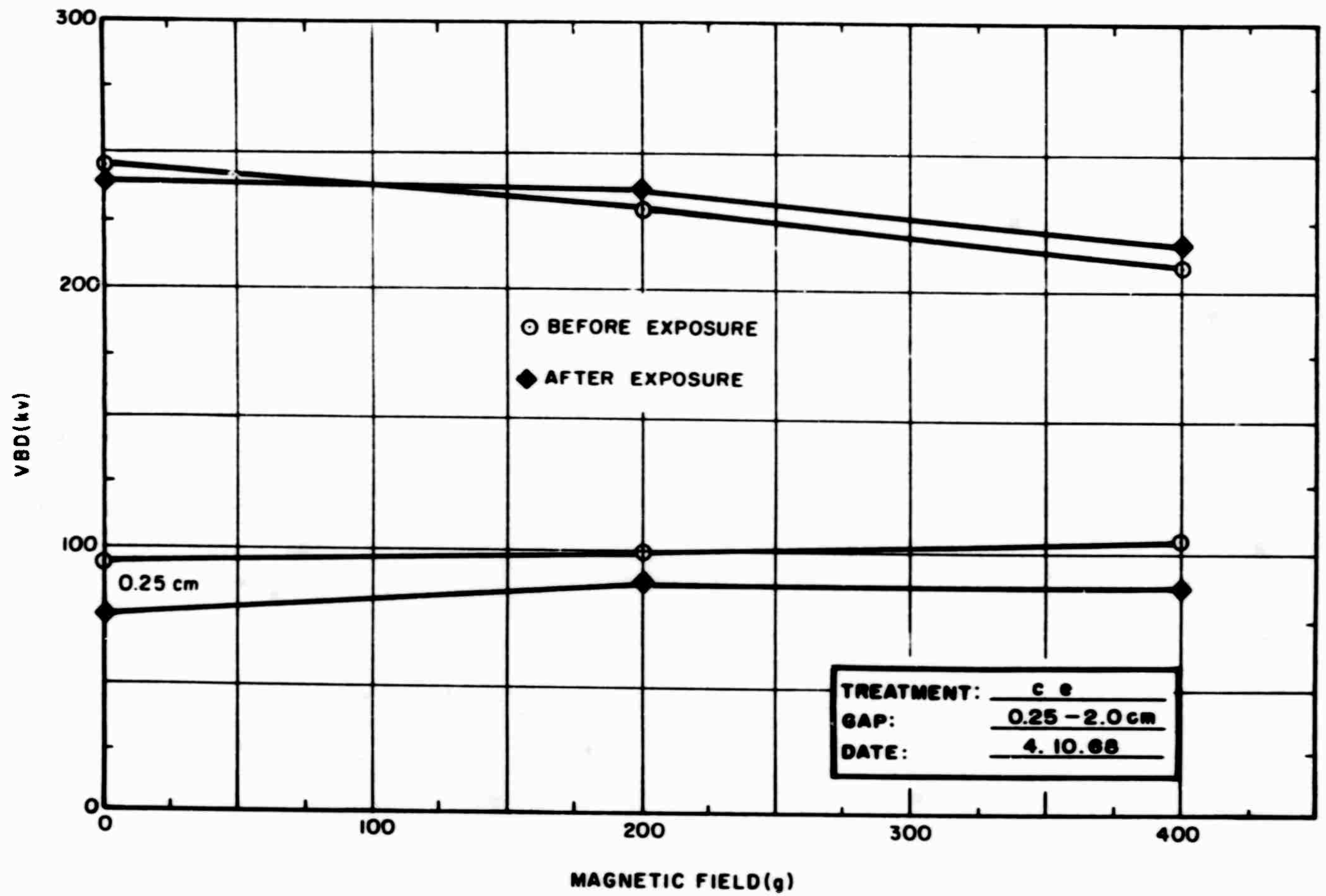

Figure 17. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment ce

1-2993

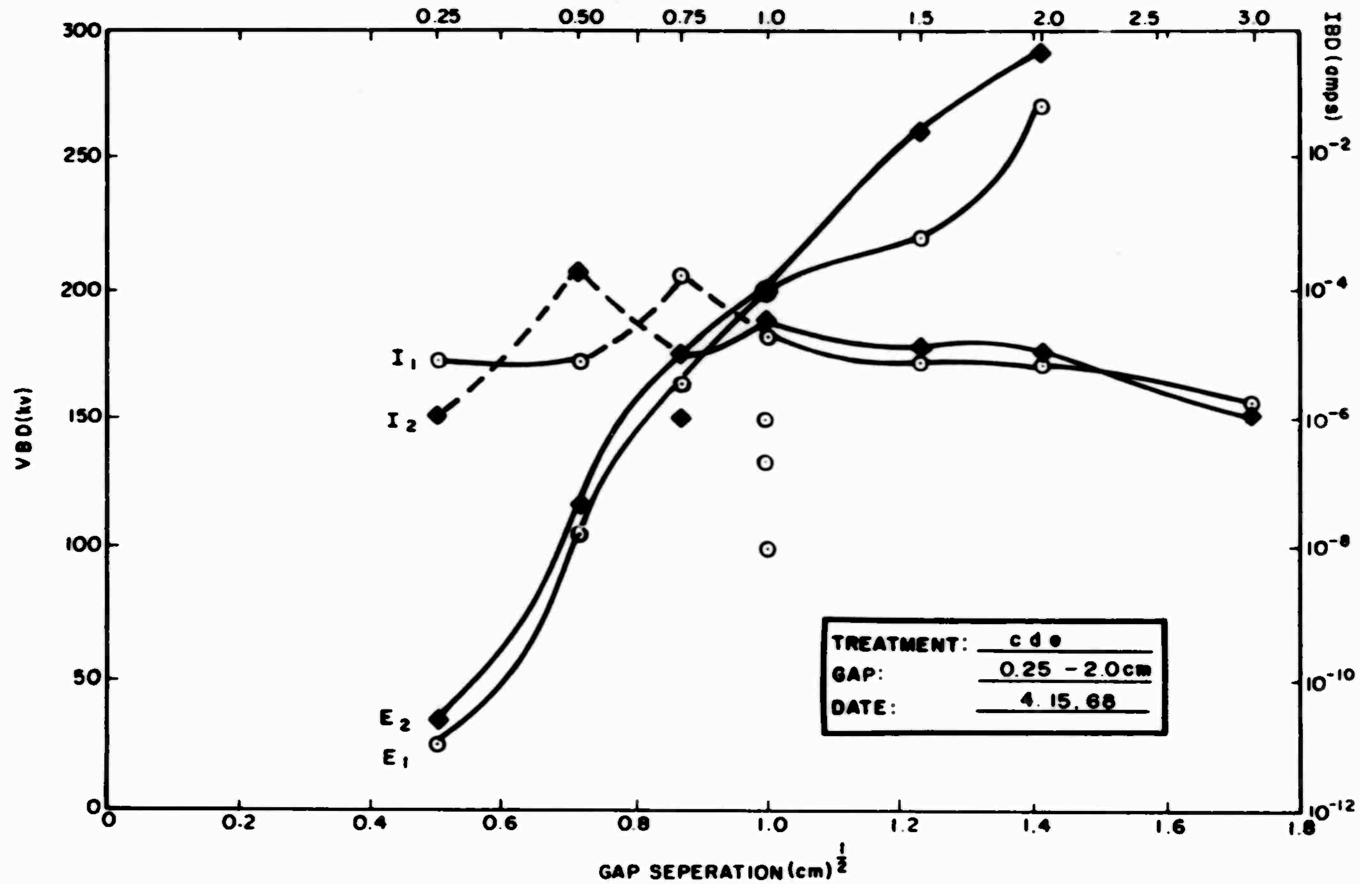

Figure 18. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment cde

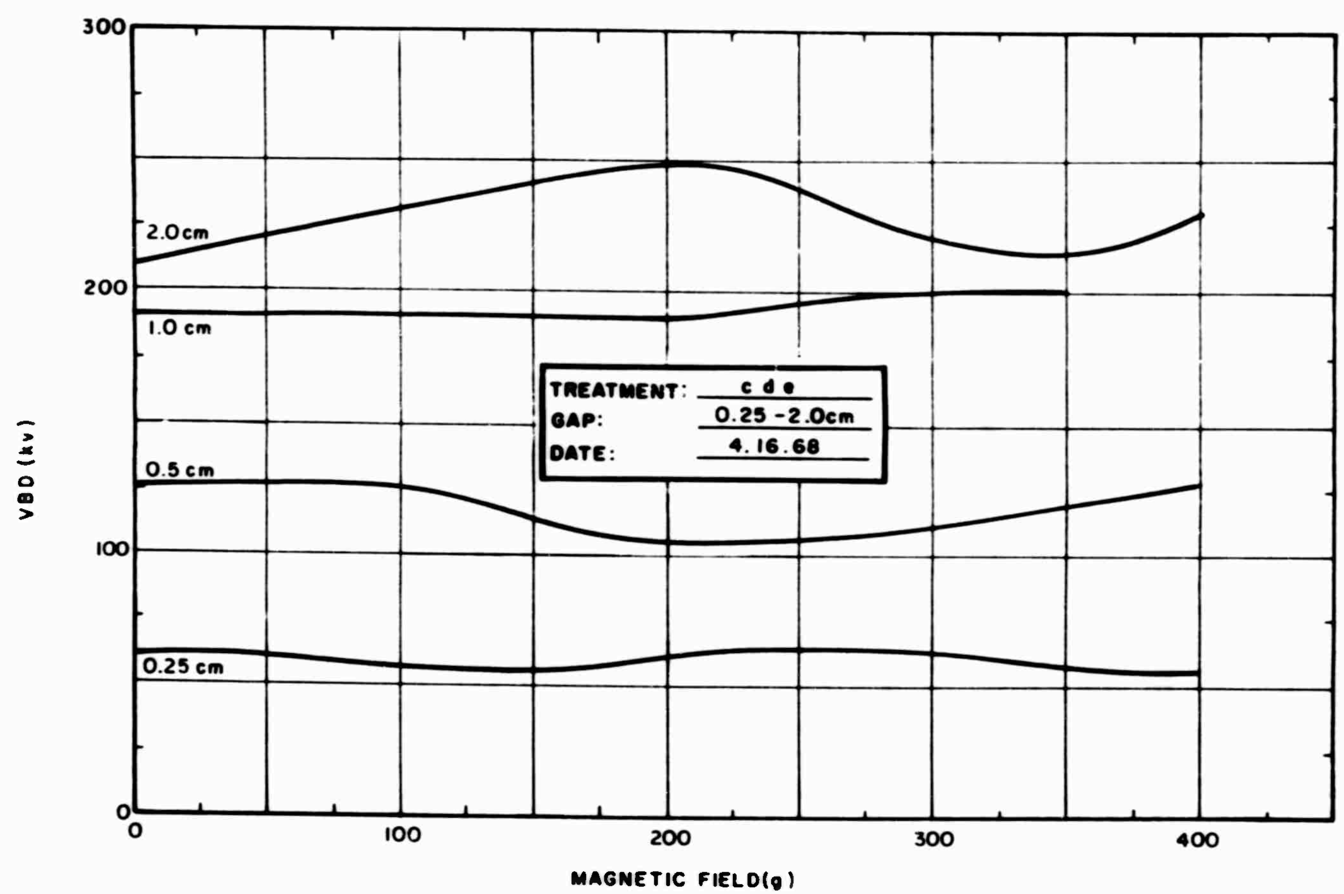

Figure 19. Variation of V_{BD} with Magnetic Field for Treatment cde

1-2995

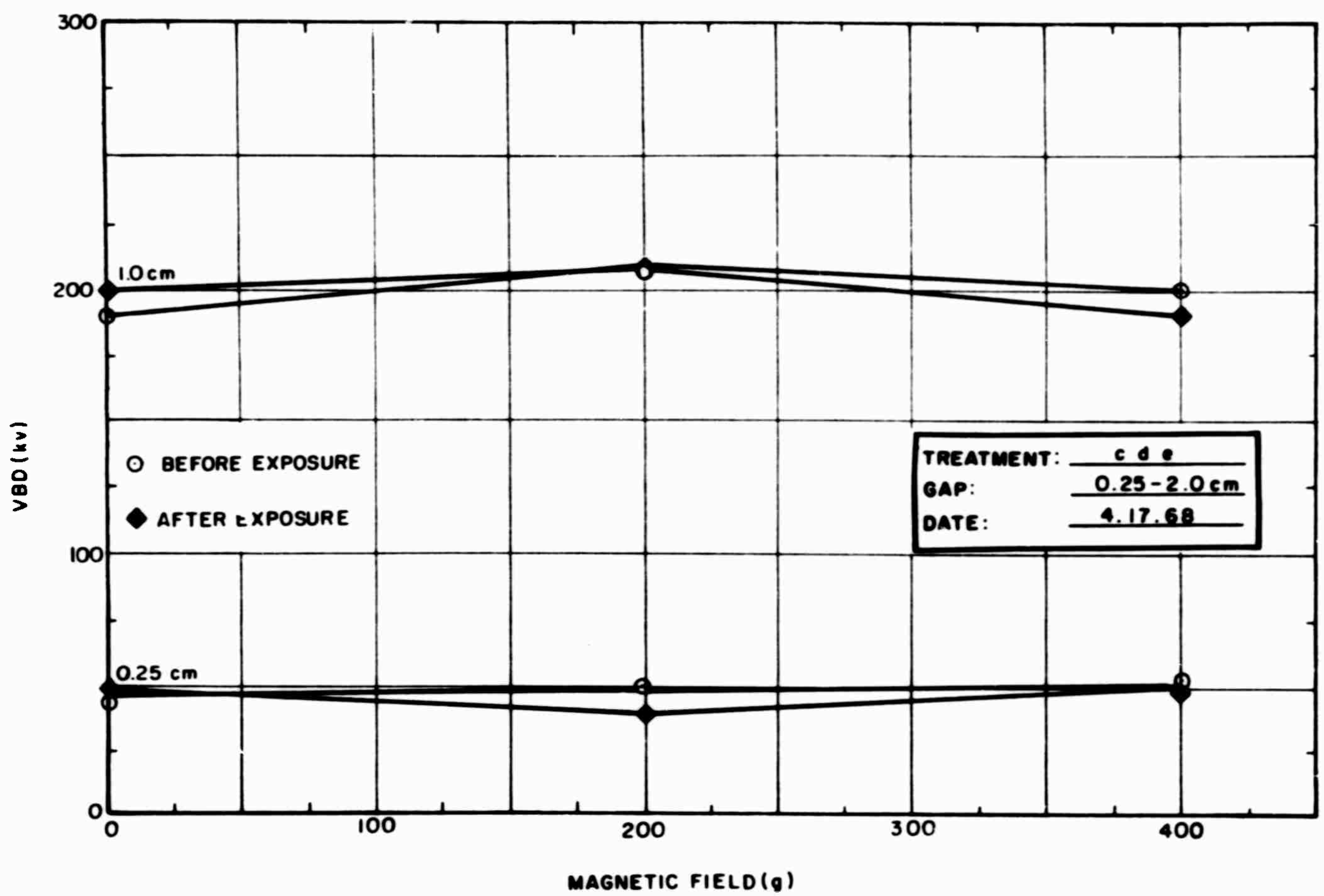

Figure 20. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment cde

1-2996

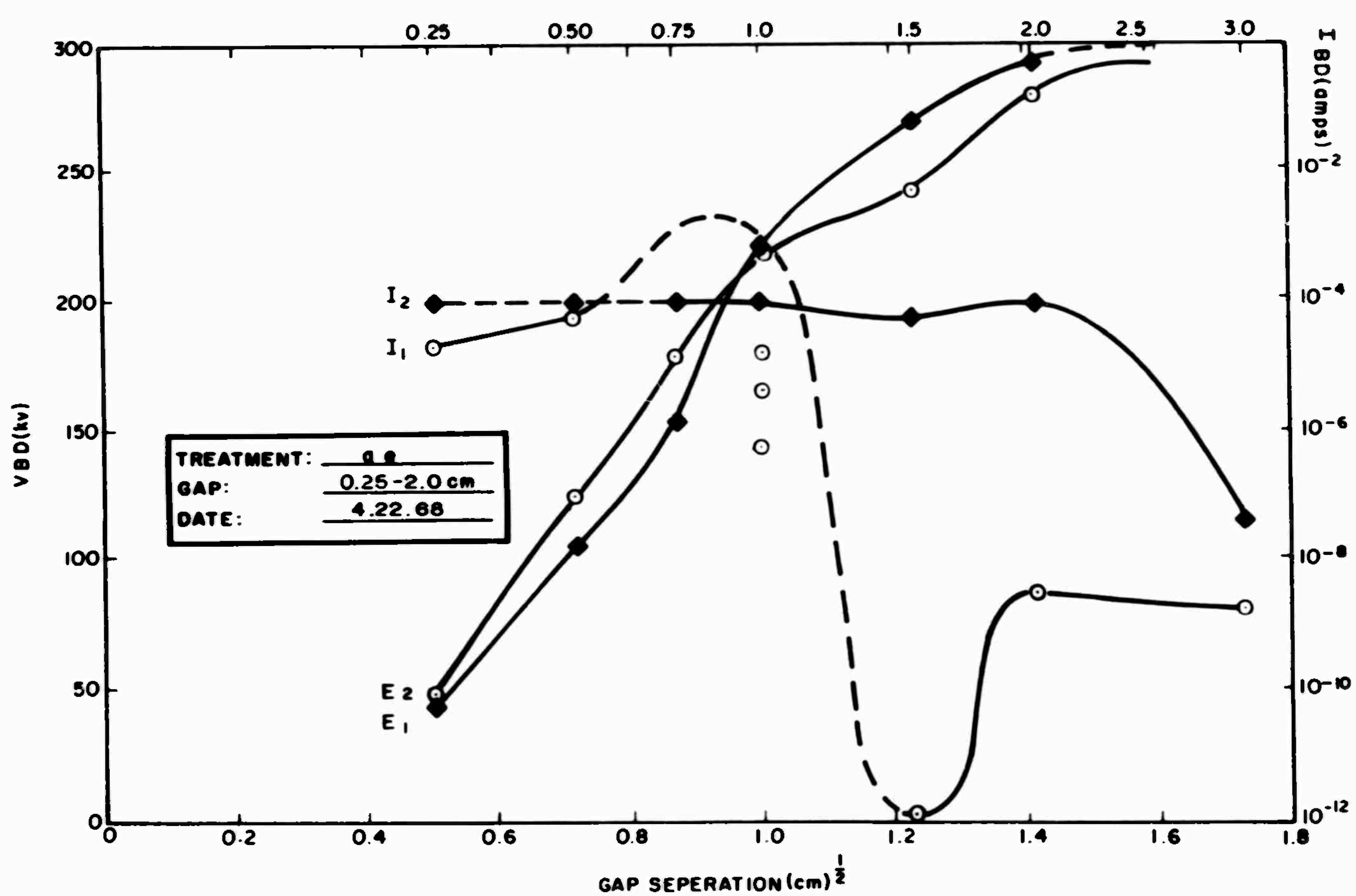

Figure 21. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment ae

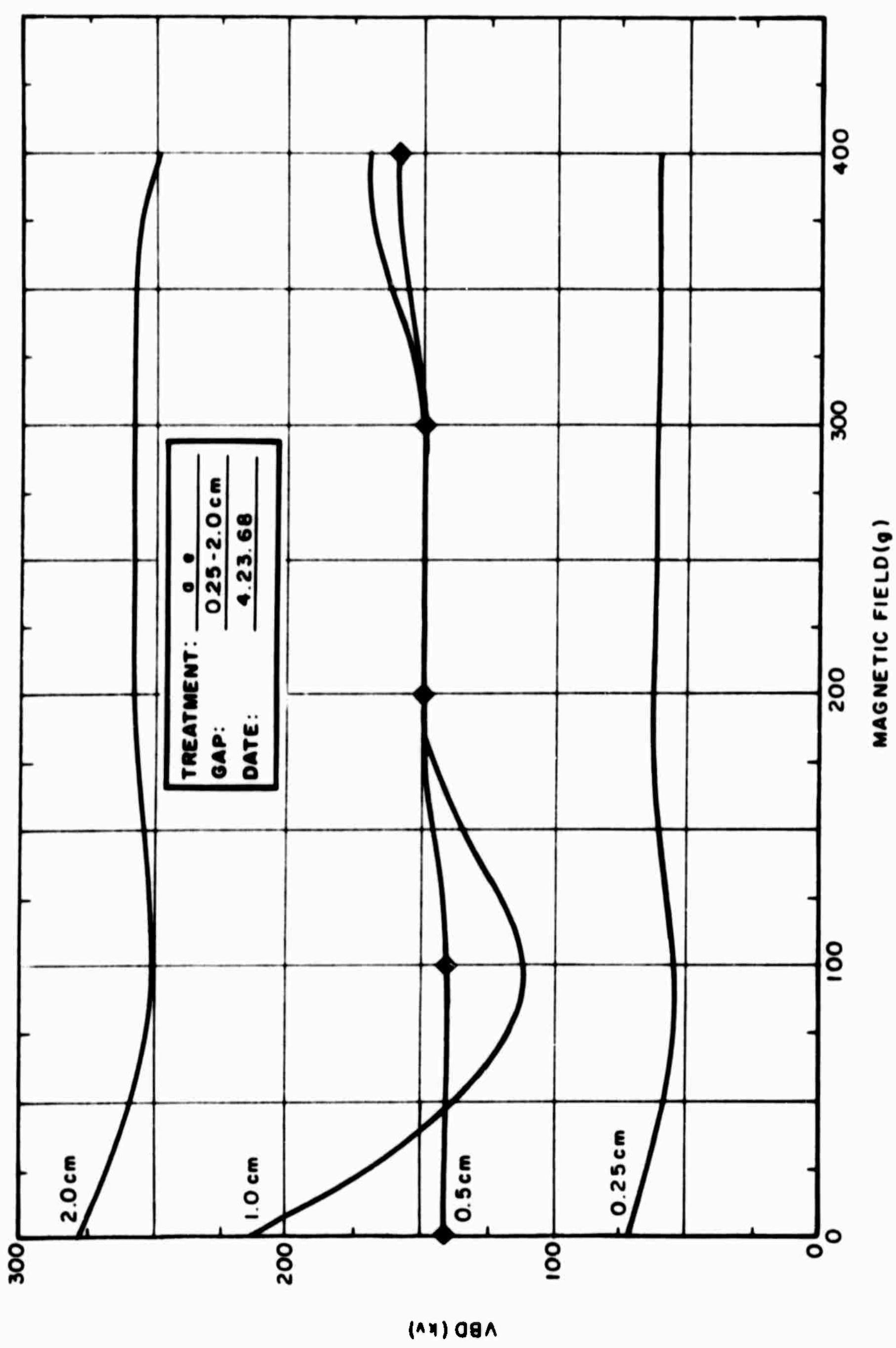

Figure 22. Variation of V_{BD} with Magnetic Field for Treatment ae

1-2998

1-2999

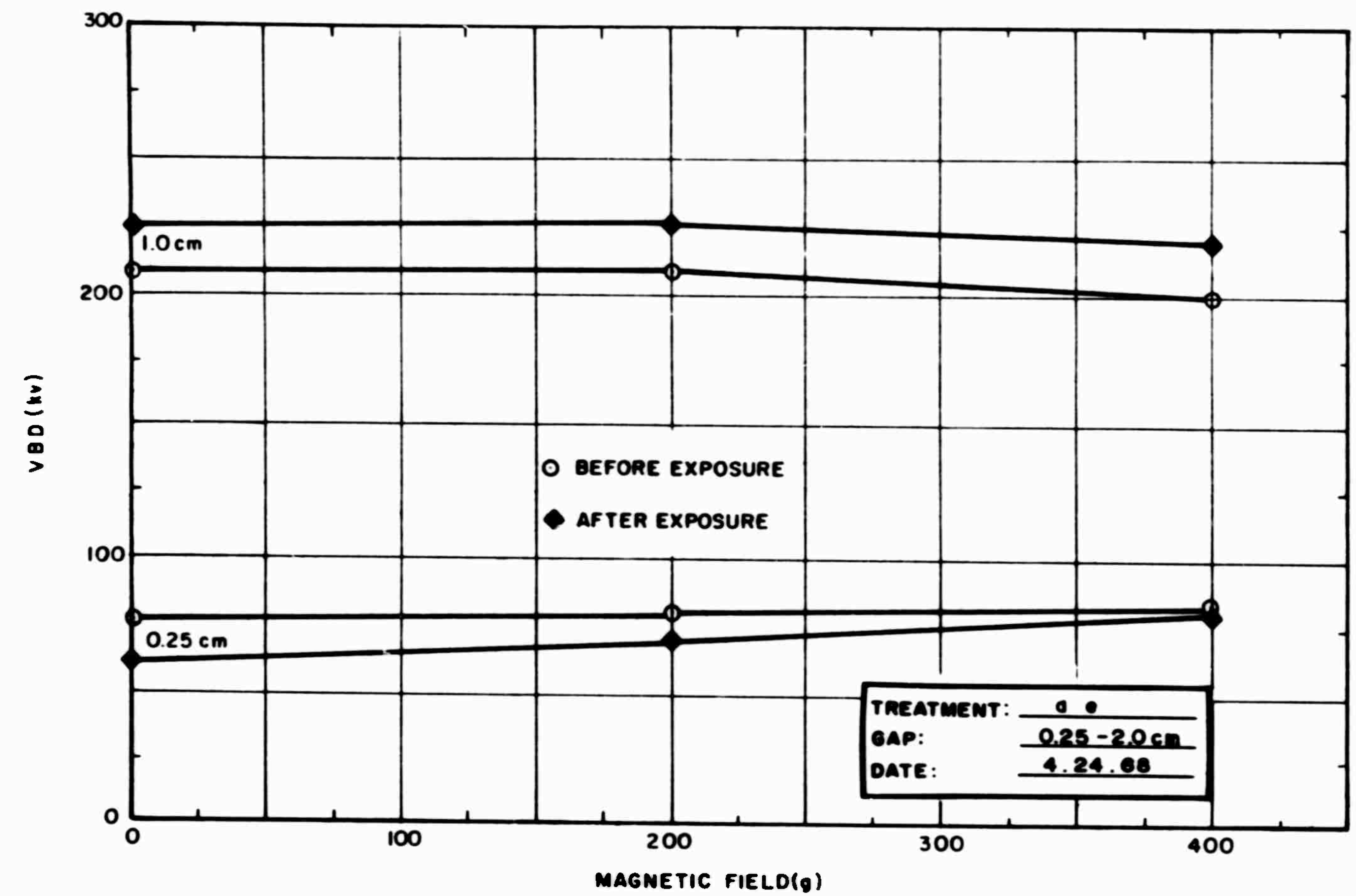

Figure 23. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment ae

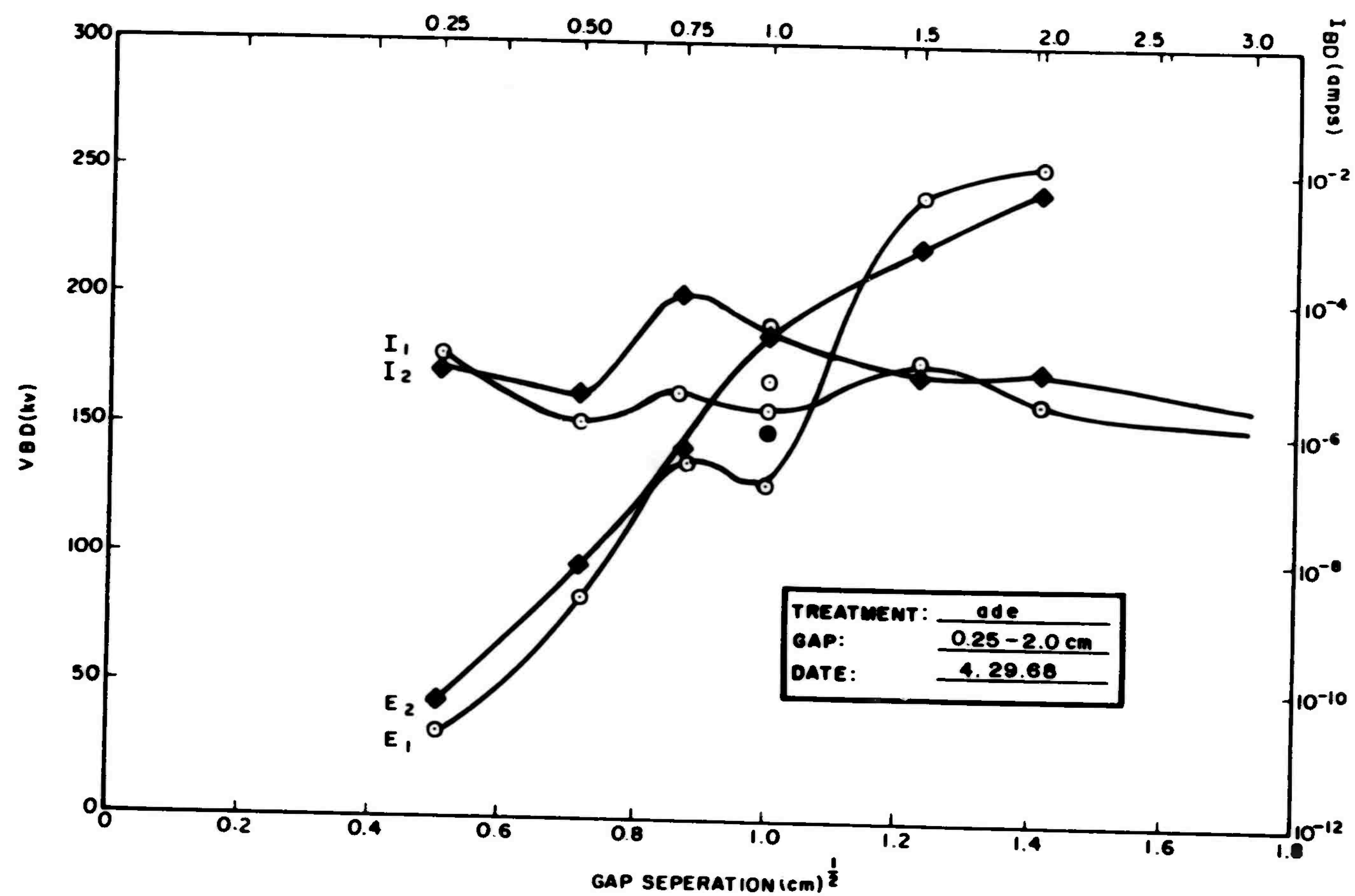

Figure 24. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment ade

1-3000

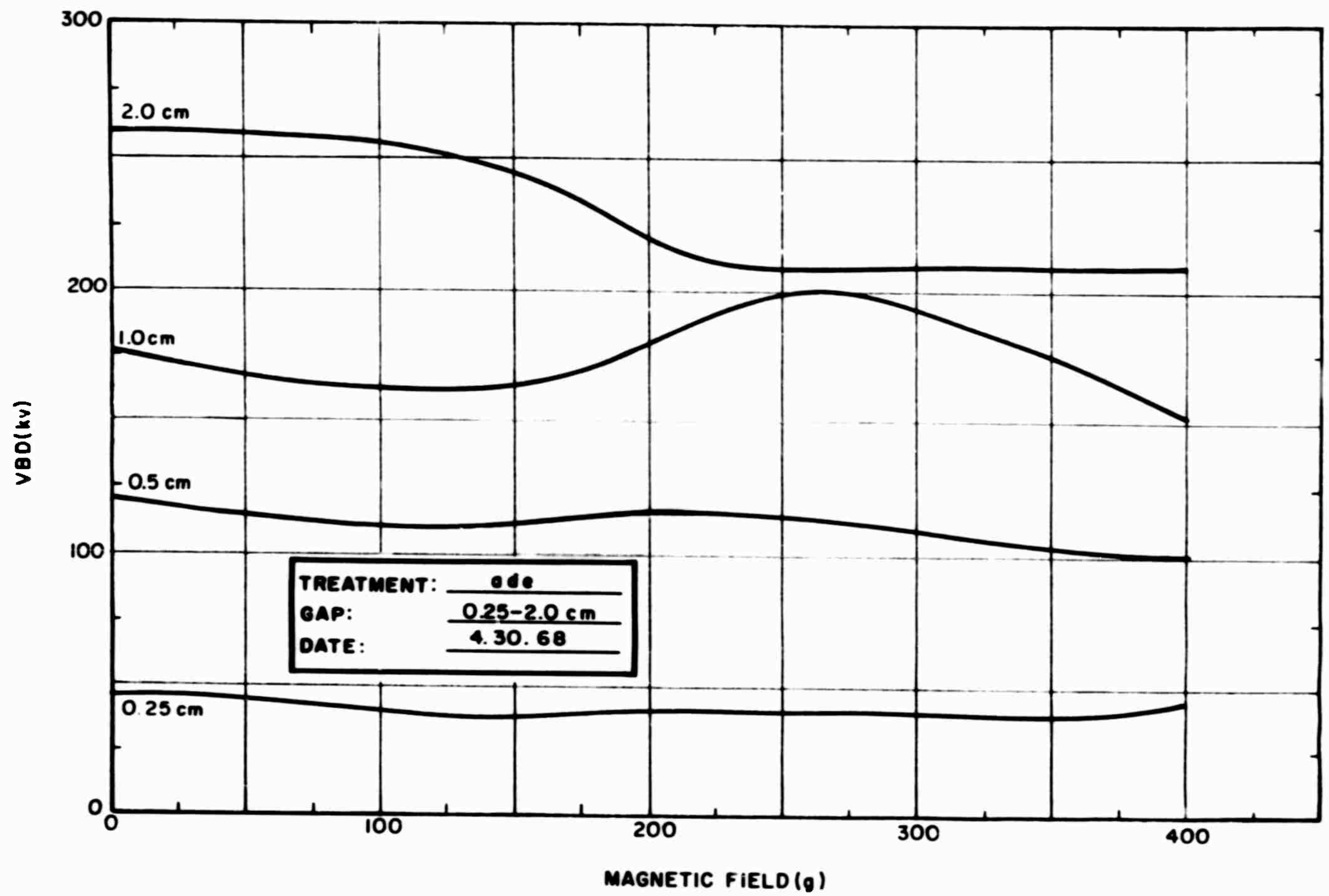

Figure 25. Variation of V_{BD} with Magnetic Field for Treatment ade

1-3001

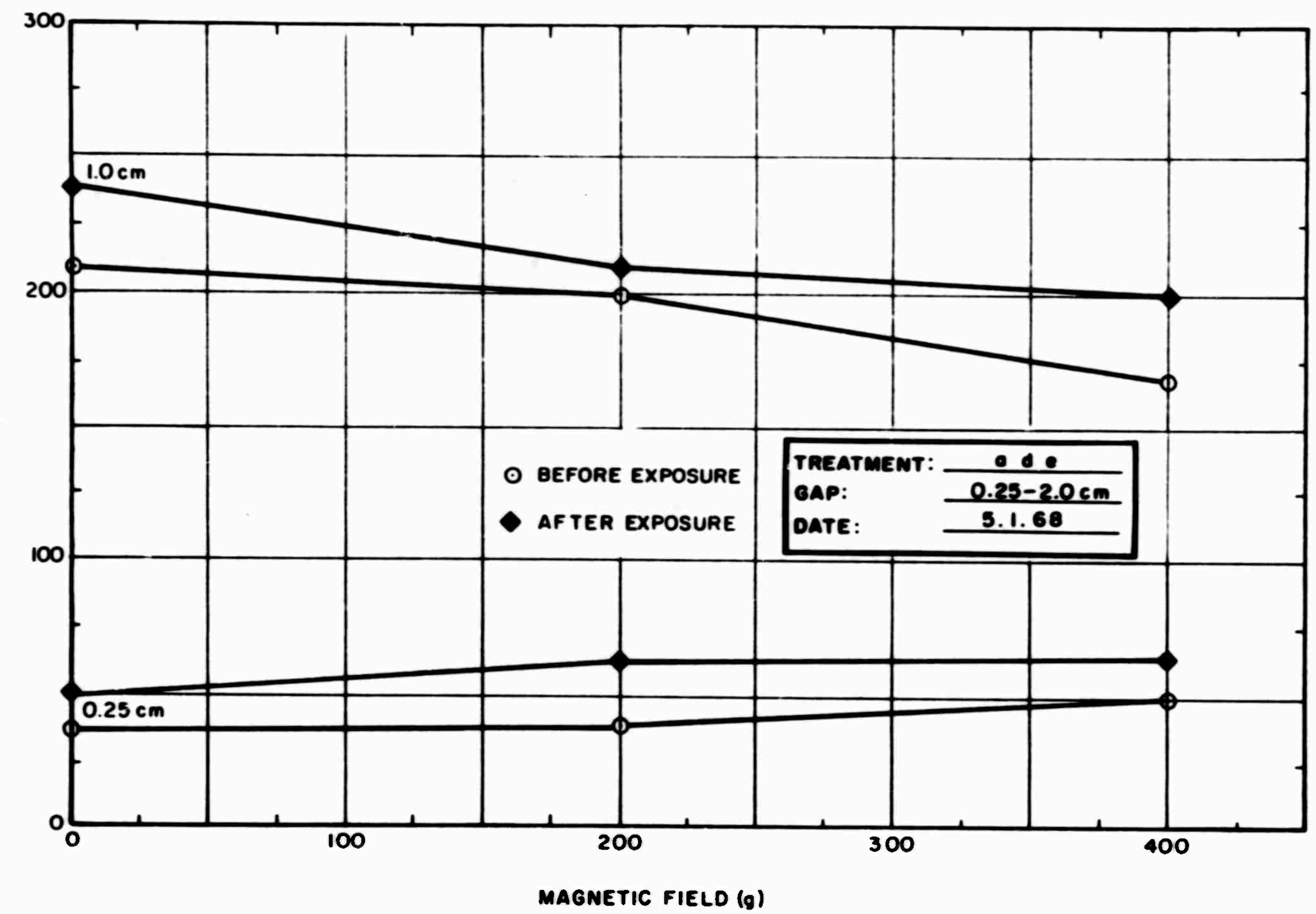

Figure 26. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment ade

1-3002

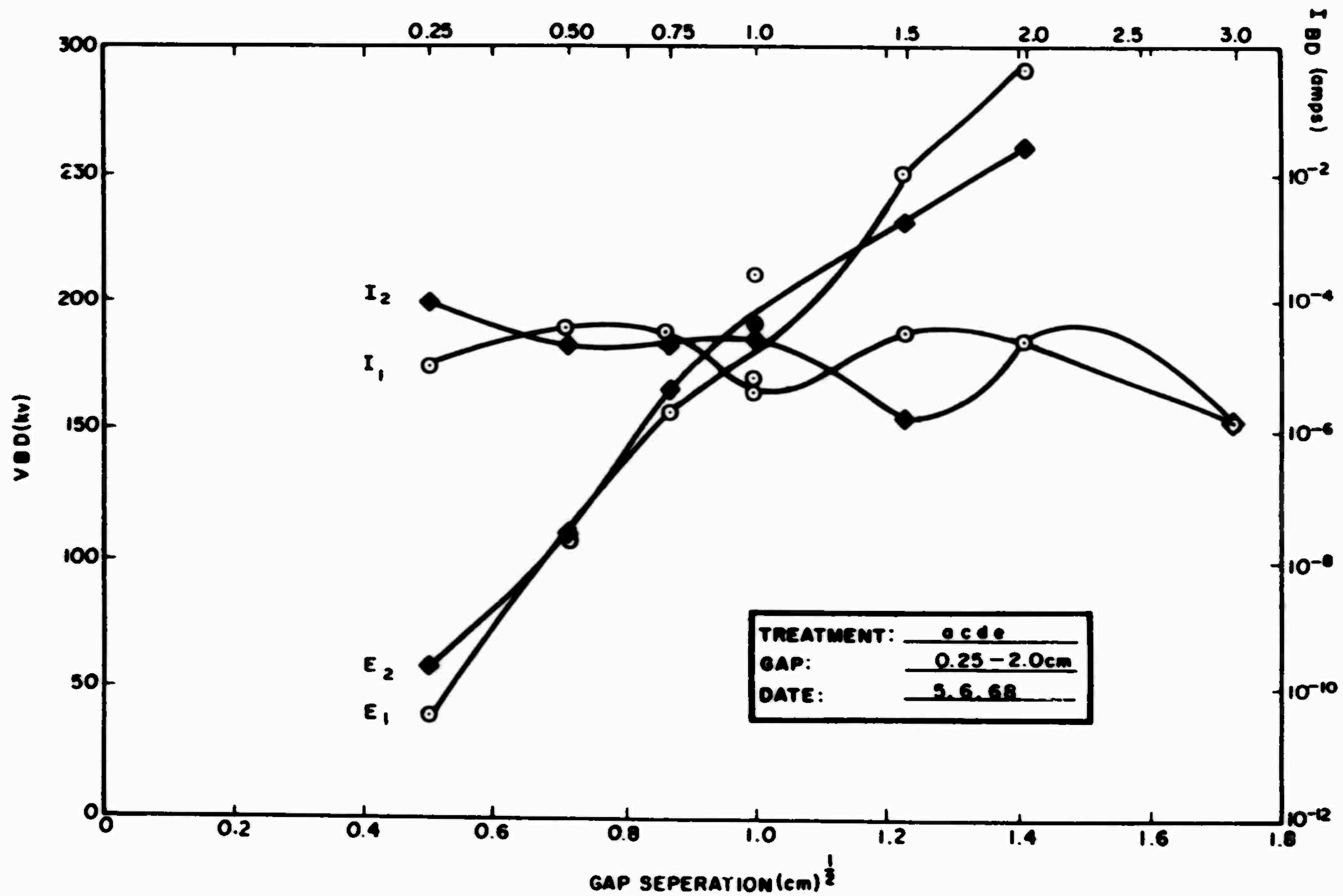

Figure 27. Variation of V_{BD} and Maximum Prebreakdown Current with Gap Separation for Treatment acde

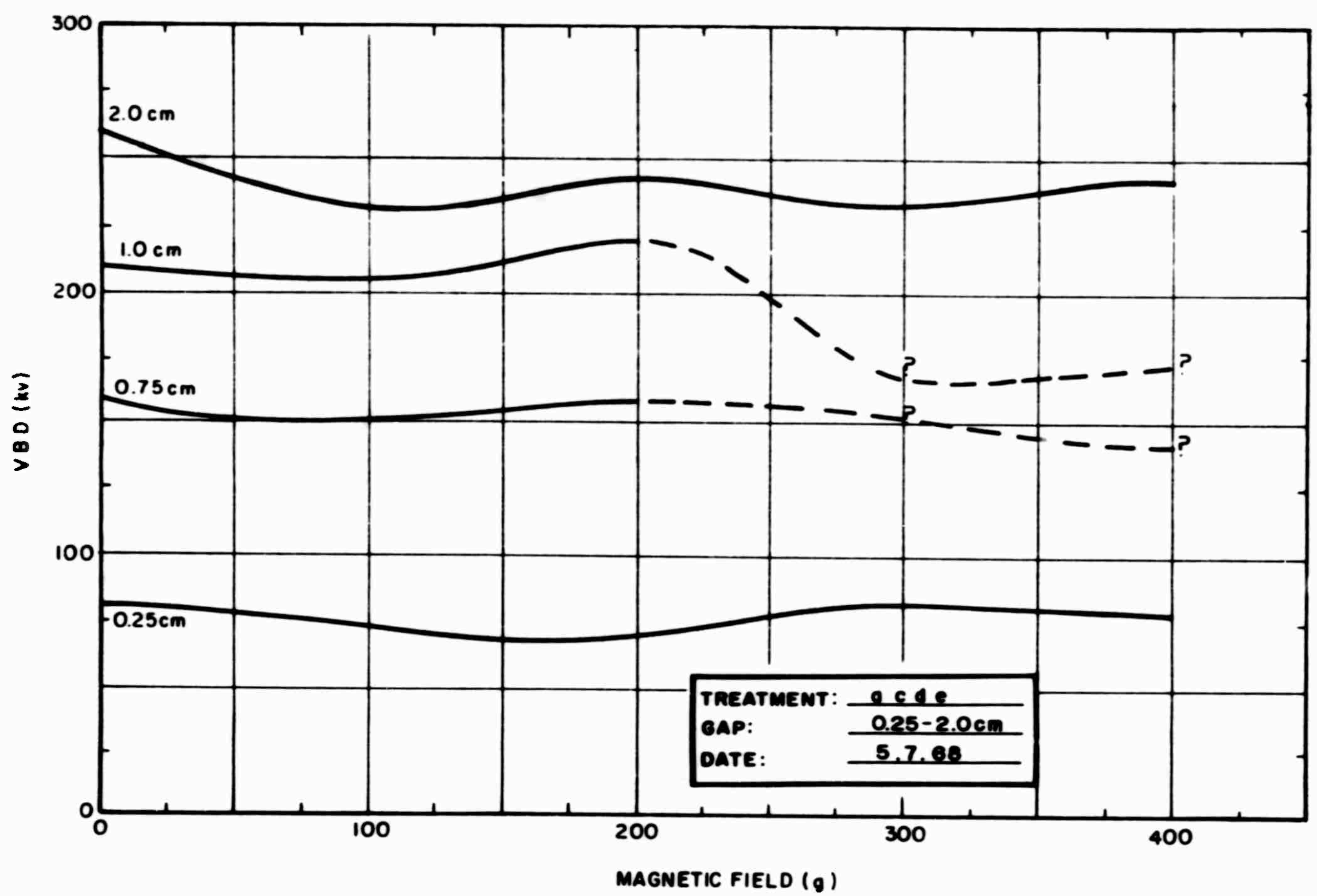

Figure 28. Variation of V_{BD} with Magnetic Field for Treatment acde

1-3004

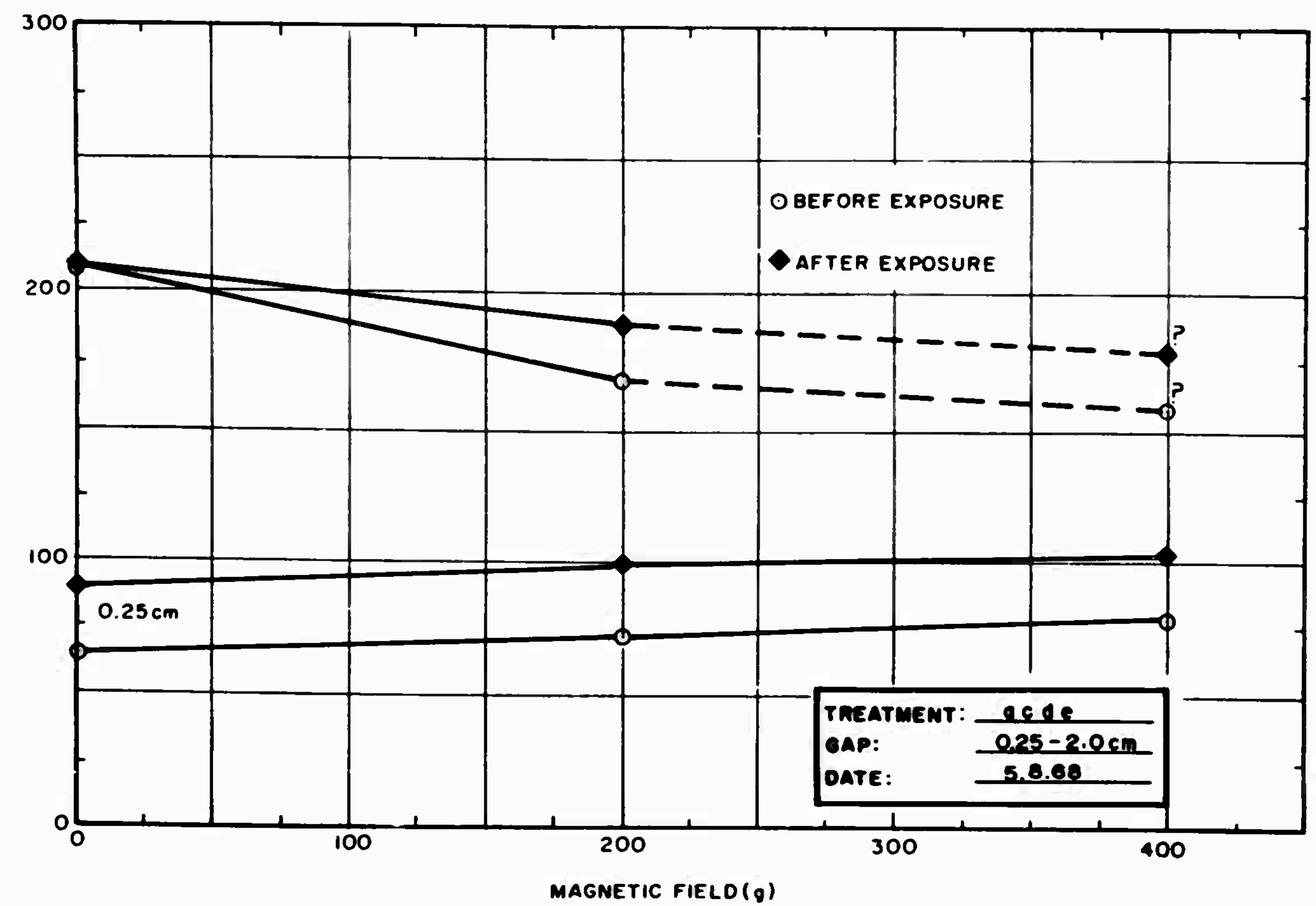

Figure 29. Variation of V_{BD} with Magnetic Field Before and After Exposure for 0.25 and 1.0 cm Gaps - Treatment acde

1-3005

SECTION 4

FUTURE EFFORT

During the next quarter, the following will be pursued:

- Continue with remaining treatments.
- Fabricate and test dielectric envelope at the end of one or two treatments.
- Investigate crowbar efficiency.
- Regular maintenance of main chamber, pumps, electrode firing system, instrumentation, high voltage power supply, magnets and their supplies.
- Analytical report on model of breakdown process.
- Analysis of first 16 treatments.
- Initiate design of next experiment.

SECTION 5

IDENTIFICATION OF PERSONNEL

The following personnel were active in the program during the period under review:

Dr. S. V. Nablo	- Vice President Director, Particle Physics Division
Dr. M. J. Mulcahy	- Project Manager
A. C. Stewart	- Engineering Manager
W. R. Bell	- Senior Electrical Engineer
M. M. Thayer	- Senior Metallurgist
A. Watson	- Senior Scientist
F. Y. Tse	- Electrical Engineer
R. M. Parsons	- Engineering Aide
D. Bryant	- Technician
R. Benoit	- Design Engineer
C. Boudreau	- Engineering Aide
L. Indingaro	- Metallurgical Technician
D. J. Maynard	- Senior Mechanical Engineer
S. K. Wiley	- Group Leader/Mechanical Engineering
Prof. H. Freeman	- Consultant Massachusetts Institute of Technology Department of Economics and Social Science
Prof. A. Argon	- Consultant Massachusetts Institute of Technology Department of Mechanical Engineering
Dr. N. E. Woldman	- Consultant Metallurgy

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1. ORIGINATING ACTIVITY (Corporate author) Ion Physics Corporation South Bedford Street Burlington, Massachusetts 01803	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

High Voltage Breakdown Study

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Fourteenth Quarterly Progress Report, 16 February 1968 through 15 May 1968

5. AUTHOR(S) (First name, middle initial, last name)

W. R. Bell, M. J. Mulcahy, F. Y. Tse and A. Watson

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Advanced Research Projects Agency ARPA Order No. 517	U. S. Army Electronics Command Fort Monmouth, New Jersey 07703 Attn: AMSEL-KL-TS

13. ABSTRACT

The results of nine further treatments are reported from a 32-block, 5-factor, full-factorial experiment now underway to investigate the main effects and interactions of the following factors: anode and cathode material (copper and aluminum), electrode treatment (hydrogen or vacuum fired), anode size and shape (Bruce or sphere). By a process of stacking, the effect of a transverse magnetic field, exposure and energy storage will also be investigated.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electrical Breakdown in Vacuum Conditioning Procedure Optical and X-Radiation Partial Pressure and Gap Current Etching						

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